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Mesopredator Movement, Abundance, and Habitat Selection in the Rainwater Basins of Nebraska

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MESOPREDATOR MOVEMENT, ABUNDANCE, AND HABITAT SELECTION IN THE RAINWATER BASINS OF NEBRASKA

by

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MESOPREDATOR MOVEMENT, ABUNDANCE, AND HABITAT SELECTION IN THE RAINWATER BASINS OF NEBRASKA

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The Rainwater Basin Wetlands of south-central Nebraska are isolated within a matrix of agriculture, resulting in varying habitat quality. Little is known about how mesopredators such as raccoons (*Procyon lotor*), striped skunks (*Mephitis mephitis*), and Virginia opossums (*Didelphis virginiana*) use the habitats available. The goals of this study were to determine the composition of mesopredators in the RWB, document their movements, abundance, and habitat selection as well as relate mesopredator presence to songbird nesting survival.

This study was conducted from May to July, coinciding with songbird breeding seasons, during 2002 and 2003. Our 13x18 km study area (~30,000 ha) was located in Clay County, in south-central Nebraska. We chose eleven proximal wetlands as study sites, encompassing a range of sizes and area of surrounding grassland, upland habitat. We included both public and private wetlands in this study.

We conducted live trapping and radio telemetry to determine the specific composition, abundance, and movements of mesopredators among the 11 study wetlands. We used a portable anesthesia machine to administer isoflurane inhaled anesthesia in the field, increasing safety for captured animals as well as investigators. We captured 43 and 35 individual mesopredators in 1345 and 1051 trap nights during 2002 and 2003, respectively. We radio-marked 25 mesopredators including raccoons (Procyon lotor),

striped skunks (Mephitis mephitis) and Virginia opossums (*Didelphis virginiana*). Using kernel-based home ranges, we determined habitat selection preferences within utilized and available habitat types. Raccoons and skunks selected landscapes containing wetlands, while opossums used them sporadically. All mesopredators also exhibited selection of corn, likely food source.

We also conducted nest searching and monitoring to evaluate songbird survival among the study wetlands. Nest survival was higher in 2003 (pooled: 36%) than in 2002 (pooled: 27%). Predator abundance and nest survival were negatively correlated each year, although the relationship was not perfect. Certainly other predators are important to songbird nest survival. Thus, local and landscape variables accounted for variation in predator presence which in turn, accounted for some variation in nest survival. Differences in wetland habitat composition such as presence of trees, at some wetlands may have increased predators in 2003, but did not affect nest survival because of high water levels. Our results suggest that landscapes with a diversity of habitat types are important in supporting a diverse mesopredator community. In addition, our study suggests that both local and landscape variables must continue to be considered when making management decisions.

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CHAPTER 1. Immobilization of mesopredators with inhaled isoflurane in the field

***Abstract*:** Inhaled isoflurane is one of a vast array of immobilizing agents available for field anesthesia of wildlife. We present information on the benefits of using inhaled isoflurane for immobilization of mesopredators for field-based research. We anesthetized captured animals in a wetland complex in south-central Nebraska with isoflurane to reduce stress on the animal and increase safety for investigators. We used a portable anesthesia machine to provide anesthesia at the capture location. During 2002 and 2003, we captured and immobilized 16 raccoons, 20 skunks, 4 opossums, 2 badgers, and 1 mink. We also radio-collared 11 raccoons and 9 skunks. Induction was smooth and uneventful for all species immobilized. Mean induction times for raccoons and skunks were 10.7 minutes (SD = 1.1) and 11.0 minutes (SD = 2.4) respectively. Mean handling times (post-induction) were 7.1 minutes (SD = 3.9) for raccoons and 7.3 minutes (SD = 4.8) for skunks. All animals, with the exception of opossums, were fully recovered within 15 minutes (raccoon: 11.1 minutes, SD = 3.5; skunk: 10.9 minutes, SD = 3.7). Radio-collared individuals did not show significantly different recovery times, compared to uncollared individuals, and individuals with longer handling times did not require longer recovery times. We suggest that in many instances, isoflurane should be chosen over the standard injectable anesthesia, ketamine. Although isoflurane requires more equipment than injectables, its ease of use and wide safety margins deem it practical for use in a variety of field applications.

INTRODUCTION

Wildlife biologists may choose among a vast array of immobilizing agents for field anesthesia. These agents are available in a variety of combinations, each varying in effectiveness relative to species, body weight, specific combinations, and dosages (Mathews et al. 2002, Seal and Kreeger 1987). A suitable anesthesia for most wildlife species must yield an animal completely unconscious and unable to perceive pain as well as provide for a complete and rapid recovery. Chemical restraint success is only complete after the immobilized animal is fully recovered and chances for competitive disadvantages are minimized following release (Osofsky and Hirsch 2000).

Recent interest in the roles of medium-sized predators (mesopredators) in ecosystems has resulted in many field experiments which have trapped or radio-marked these animals (Kuehl and Clark 2002, Lariviere and Messier 2000, Phillips et al. 2003, Tuyttens et al. 1999). Thus, the need for effective anesthesia for mesopredators has increased.

A variety of injectable anesthetic agents have been used successfully to immobilize mesopredators in the field. Ketamine has been used alone to immobilize raccoons (*Procyon lotor*; Bigler and Hoff 1974), striped skunks (*Mephitis mephitis*; Rosatte and Hobson 1983), and Virginia opossums (*Didelphis virginiana*; Feldman and Self 1971). Often, ketamine is combined with xylazine, acepromazine, or medetomidine to reduce necessary dose and volume as well as reduce time needed to produce anesthesia and provide a relaxed anesthesia (Pond and O'Gara 1996). Ketamime combinations have been used to immobilize various mammals such as raccoons (Belant 1995*a*, Deresienski and Rupprecht 1989, Gehrt et al. 2001), mink (*Mustela vison*; Arnemo and Soli 1992),

and red fox (*Vulpes vulpes*; Kreeger et al. 1990, Travaini et al. 1992). Telazol (tiletamine and zolazepam) has been used to immobilize raccoons (Gehrt et al. 2001), skunks (Lariviere and Messier 1996*b*), and badgers (Travaini et al. 1994). Fentanyl-droperidol and phencyclidine have been used to immobilize opossums (Feldman and Self 1971). Finally, pentobarbital sodium has been used to immobilize skunks (Verts 1960). Dosages of these injectable immobilizing agents are all body weight dependent and few serious side effects were reported in the preceding studies. Induction times reported were rapid (usually <5 minutes) for these drugs but recovery times were prolonged in many cases (20 minutes – 4 hours).

Inhalation anesthetics have also been used in field settings, limited mainly to young animals or species small enough to be manually restrained or enclosed in a bag or box (Seal and Kreeger 1987). Inhalation anesthetics offer good control over the depth and duration of anesthesia and they follow the dose-response concept; the effect increases as the dose increases (Kreeger et al. 1998, Seal and Kreeger 1987). Generally, the chosen anesthetic is put on an absorbent medium and placed in an enclosed area with the animal (Belant 1995*b*, Feldman and Self 1971, Lariviere and Messier 1996*a*, Taulman and Williamson 1993). Taulman and Williamson (1993) reported that use of chloroform or halothane inhalant anesthesia in raccoons avoided problems associated with incorrect doses administered by injections and provided a shorter recovery period. Lariviere and Messier (1996*a*) reported that halothane provided an adequate anesthesia for short handling procedures (approx. 1 minute) in striped skunks. Feldman and Self (1971) used methoxyflurane in opossums as a non-explosive option over ether.

Typically used in veterinary practice, isoflurane inhaled anesthesia has recently become suitable for field use. Isoflurane is an isomer of enflurane that yields smooth induction and recovery for anesthetized animals (Seal and Kreeger 1987). It has been successfully used in field studies for a wide range of wildlife species including muskrats (*Ondatra zibethicus*; Belant 1995*b*), beaver (*Castor Canadensis*; Breck and Gaynor 2003), Siberian polecats (*Mustela eversmanni*; Gaynor et al. 1997), Steller's sea lions (*Eumetopias jubatus,* adults and pups; Heath et al. 1996, 1997), and black-footed ferrets (*Mustela nigripes*; Kreeger et al. 1998). This method of anesthesia requires fewer different types of drugs and, because needles are not used, potential human contact with the drug is greatly reduced. Some commonly used injectable drugs are lethal to humans at a fraction of the doses used for immobilization of most wild species (Seal and Kreeger 1987). Not all injectable agents and their various combinations are completely reversible and many are associated with prolonged recovery times (Mathews et al 2002). Kreeger et al. (1998) reported that black-footed ferrets appeared more physiologically normal under isoflurane than under injected medetomidine and ketamine.

We needed to find an anesthesia that would be suitable for handling multiple species for short-duration procedures in a field study of mesopredators. Thus, we chose to use isoflurane gas for its simplicity, rapid induction and recovery, and minimal side effects as reported in the previous studies. However, none of these studies examined the effects of prolonged anesthesia on recovery times. And, no previous study has documented the use of isoflurane to anesthetize mesopredators in North American wetland systems (e.g. raccoons, striped skunks, Virginia opossums). Our study is the first to document the simultaneous use of isoflurane on a wide range of species.

The objectives of this study are to 1) determine efficacy of isoflurane gas as a field anesthesia for a suite of mesopredators, and 2) determine the effect of anesthetized handling time on animal recovery time.

METHODS

Study area and target species

This research was conducted during 2002 and 2003 as part of a large, concurrent mesopredator study in the Rainwater Basin wetlands of south-central Nebraska. The Rainwater Basin is a complex of isolated wetlands existing in a highly fragmented agricultural landscape. Our study area encompassed 11 wetlands consisting of both publicly and privately managed areas.

We conducted live trapping on each wetland for a 4-5 day period twice between May and August each year. Raccoons and striped skunks were the primary target species of this study based on abundance, ease of capture, and ability to carry a radio transmitter. We radio-marked a sub-sample of raccoons and skunks using 30g radio collars (model MI-2, Holohil Systems Ltd. Corp, Ontario, Canada). Other mesopredators known to inhabit this region include Virginia opossums and American badgers (*Taxidea taxus*).

Field anesthesia methods

We anesthetized captured animals with isoflurane (MWI Veterinary Supply Co., Nampa, ID) to reduce stress on the animal and increase safety for investigators. We used a portable anesthesia machine (designed by Dr. R.B. Heath, DVM, Seven Seven Anesthesia, Fort Collins, CO) to provide anesthesia at the capture location (Figure 1.).

The set-up was fully portable, easily constructed and collapsed in only a few minutes, and fit easily into its own large carry case (weight: 11.5 kg, not including carrying case). The unit consisted of a vaporizer connected to a Baines non-rebreathing circuit with side port bag and valve. Non-rebreathing systems are light-weight, offer reduced breathing resistance, and are useful for smaller animals and individuals with respiratory problems that may not be immediately apparent in the field (Lerche et al. 2000). Use of a precision-calibrated vaporizer allowed us to take advantage of the control advantages offered by inhalation anesthetics (Seal and Kreeger 1987). The entire machine sat on a telescoping tripod that adapted to uneven terrain. The vaporizer was connected to a portable medical oxygen cylinder (size E) using standard circuitry.

We constructed an induction chamber that accommodated various sized animals by modifying a blue plastic Rubbermaid® outdoor garbage can (dimensions: diameter, top = 48 cm and base = 38 cm; height = 78 cm). We chose to use a tall, cylindrical chamber to make it difficult for the animal to jump out when we transferred it from the trap to the chamber. The chamber also kept the animal shaded from the sun during induction. Similar to shielding the animal's eyes with a cloth (Mathews et al. 2002), the darkened chamber helped to quiet the animal, promoting a smooth induction. Clear plastic (Gaynor et al. 1997), Plexiglas® (Kreeger et al. 1998), or wooden (Balser and Kinsey 1962) boxes as well as transparent polyethylene bags (Mathews et al. 2002) previously used as induction chambers for inhalation anesthesia were inadequate for our multi-species study in a temperate grassland/wetland landscape because of the wide range of animals sampled.

We constructed a plunger to seal the animal into the chamber and restrict the amount of space to be filled with the isoflurane/oxygen mixture needed to anesthetize the animal. The plunger (dimensions: top diameter: 46 cm, base diameter: 35 cm, height: 14 cm) was constructed from a plastic tub (#H11501, Wal-Mart Stores, Inc., Bentonville, AR) cut to fit the opening of the garbage can. A 64-cm^2 window was cut into the bottom of the tub, fitted with Plexiglas® and reinforced with plywood so that we could observe the animal while in the chamber (Figure 2). The top, outer edge of the plunger was fitted with a bicycle inner tube to create an airtight seal with the chamber wall. We attached handles to the base of the plunger to protect our hands from the animal inside the chamber as the plunger was depressed to a level just above the animal. To connect the chamber to the anesthesia machine, we fitted a short rubber pipe into a hole cut through the floor of the plunger in which a hose was fitted to administer the anesthesia (Figure 2).

We transferred captured animals from a live trap into the induction chamber. Once the animal was inside the chamber, we depressed the plunger to a depth of approximately 50 cm from the top of the chamber. Exact plunger depth depended on the size of the animal. Because isoflurane anesthesia dose is not body-weight dependent, we did not need to weigh captured animals before induction.

We administered a concentration of 5% isoflurane in 3 L of oxygen per minute. After approximately 10 minutes, we checked the animal to evaluate the degree of immobilization, and more time was allotted when necessary. Complete immobilization was defined by unresponsiveness to stimuli, and we calculated induction time as the time the inhalant gas was turned on until the animal was removed from the chamber. Upon complete immobilization, we removed the animal from the chamber, decreased the

concentration of isoflurane to 3% in 3 L of oxygen per minute, and placed a small, standard nose cone fitted with a rubber ring over the animal's muzzle to maintain immobilization during handling. The animal was placed on a foam mat during handling to reduce potential heat loss (Mathews et al. 2002).

We defined handling time as the amount of time the animal was out of the chamber, with a nose cone securely over its nose and mouth. While under anesthesia, the animal was sexed, weighed, and ear tagged and a sub-sample was marked with a radio-collar. Recovery began immediately upon breathing fresh air (Dr. K. Amass, DVM; Dr. C. Morgan, DVM, personal communications). We immediately placed the animal in a transport kennel after the anesthesia was turned off and allowed the animal to recover. Complete recovery was determined by alertness, ability to stand upright, and ability to walk without stumbling. We calculated recovery time as the time from removal of the nose cone until release. Each animal was released at its capture site after it was fully recovered, and all equipment was thoroughly disinfected with bleach wipes between individuals. We attempted to locate radio-marked animals the night after marking to evaluate movement following anesthesia induction. The University of Nebraska-Lincoln's Institutional Animal Care and Use Committee (IACUC) approved our research methods prior to our field work (IACUC Permit # 01-12-075).

Statistical analysis

Here, we focus our statistical analyses on raccoons (n = 16) and skunks (n = 20), although we also used isoflurane anesthesia on opossums (n = 4), badgers (n = 2), and mink (n = 1). We recorded the time at four points: (1) when the anesthesia gas was

initially turned on, (2) when immobilization was achieved and the level of isoflurane/oxygen gas was reduced, (3) when the nose cone was removed, and (4) when the animal was released. We used a two-sample t-test to test for differences in mean induction, handling, and recovery times among species as well as to test for differences between 2002 and 2003.

Some animals in our sample were radio-marked with a collar. Because of the time needed to attach the collar, radio-marked individuals spent more time under anesthesia (handling time) than individuals that did not receive radio collars. We used a regression to determine if recovery varied with regard to handling time.

RESULTS

During 2002 and 2003, we captured and immobilized 16 raccoons (2002: 10; 2003: 6), 20 skunks (2002: 10; 2003: 10), 4 opossums (2002: 2; 2003: 2), and 2 badgers (2003). In 2002, we also immobilized one mink. We radio-marked 11 of 16 raccoons and 9 of 20 skunks captured. Each animal was only immobilized once during our study as we did not recapture any animals.

Induction was smooth and uneventful for all species immobilized. Mean induction times did not differ for raccoons and skunks ($t_{27} = 0.43$, $P = 0.33$). Induction time for the two badgers was higher than for raccoons and skunks, possibly due to their excited states when anesthesia was induced. The four opossums had variable induction times (Table 1).

Mean handling times did not differ for raccoons and skunks ($t_{34} = 0.16$, $P = 0.44$). There was, as expected, a significant difference in handling times for collared versus

uncollared individuals (t_{30} = 5.91, $P < 0.001$). Mean handling time for collared individuals was 9.9 minutes (SD = 3.9) and uncollared individuals was 3.9 minutes (SD = 2.1).

Recovery was also smooth and uneventful. All animals, with the exception of opossums, were fully recovered within 15 minutes (Table 1). Collared individuals did not show significantly different recovery times, compared to uncollared individuals (t_{29} = 0.95, $P = 0.17$). Individuals with longer handling times did not require longer recovery times (slope = -0.12, $R^2 = 0.02$, $P = 0.41$). Induction, handling, and recovery time did not vary between years ($P > 0.05$).

DISCUSSION

Immobilization side effects

We did not observe any adverse effects or deaths as a result of isoflurane immobilization in any of the species studied. The most common immobilization complication is respiratory depression (Seal and Kreeger 1987). Kreeger et al. (1998) reported respiratory depression and one case of respiratory arrest while using isoflurane in black-footed ferrets (n = 8) during 30-minute procedures. Breck and Gaynor (2003) observed decreased heart rates as well as decreased respiratory rates in a surgical procedure (60 minutes) using isoflurane in beavers. Arrhythmias are rare but do present a potential adverse effect of isoflurane anesthesia (Belant 1995*b*, Seal and Kreeger 1987). Heath et al. (1996) reported complications in a study of Steller's sea lions using an isoflurane vaporizer that had been tipped on uneven rocks to an angle incompatible with proper valve operation.

Isoflurane is likely one of the least toxic of inhalation anesthetics available today (Belant 1995*b*). Ether is a versatile anesthetic, producing good muscle relaxation, but it irritates respiratory passages, and nausea, vomiting as well as hyperglycemia may occur (Seal and Kreeger 1987). Chloroform causes liver cancer in mice and kidney tumors in rats (Taulman and Williamson 1993). It is obsolete and has been replaced by safer and more effective compounds (Seal and Kreeger 1987). Circulatory depression and rapidly progressing reduced blood pressure are reported side effects of halothane in raccoons (Taulman and Williamson 1993). In general, halothane also depresses temperature regulation centers, decreases gut motility, and only moderately relaxes muscles (Seal and Kreeger 1987). Sevoflurane is a newer inhalant anesthesia that allowed for a more rapid change in depth of anesthesia and produced a more rapid induction and recovery than isoflurane in Siberian polecats (Gaynor et al. 1997). However, Heath et al. (1997) chose isoflurane over sevoflurane because of costs and field suitability. Methoxyflurane is the most potent of the gas anesthetics, but induction and anesthesia depth changes are slow (Seal and Kreeger 1987). There is also a substantial risk of overdose if an uncalibrated method is used with modern highly volatile anesthetics such as methoxyflurane (Mathews et al. 2002).

Ketamine is probably one of the most widely used drugs for wildlife immobilization (Seal and Kreeger 1987). We suggest, however, that a highly efficient inhaled anesthetic option with few side effects may be an appropriate choice for biologists, given the unwanted side effects associated with ketamine and ketamine mixtures. Dzialak et al. (2002) reported that use of ketamine alone was associated with a shallow immobilization with increased muscle tension and labored respiration in fishers

(*Artes pennanti*), and Bigler and Hoff (1974) noted a slight increase in tachycardia in raccoons as dosage increased. Ketamine may also cause a dose-dependent respiratory depression, but laryngeal and pharyngeal reflexes are usually maintained (Seal and Kreeger 1987). Other potential side effects of ketamine include apnea, excessive salivation, and hypothermia (Morin and Berteaux 2003). Ketamine alone is also associated with prolonged recovery times from one to five hours (Fowler 1995).

Ketamine is often combined with other drugs to increase immobilization effectiveness and decrease the required dose of each agent (Fowler 1995). However, spasms, twitching, compulsive licking, hyperflexive stages, convulsions, and violent movements during recovery as well as hypersalivation, vomiting, and varied respiration were observed side effects of ketamine and xylazine (Belant 1995*a*, Deresienski and Rupprecht 1989, Fuglei et al. 2002, Telesco and Sovada 2002). Fuglei et al. (2002) also noted spontaneous recovery in a study of arctic fox (*Alopex lagopus*), with this drug combination. Yohimbine has been successfully used to reverse ketamine and xylazine immobilization in raccoons, significantly decreasing recovery time (Deresienski and Rupprecht 1989).

Another common drug combination used in mesopredator research in the field is tiletamine and zolazepam, also known as telazol. Used alone, tiletamine may cause convulsions in some species, but when it is combined with zolezepam this side effect is reduced (Viggers and Lindenmayer 1995). Some side effects include hypersalivation, excessive licking, variable respiratory rates, tachycardia, and mild hyperthermia (Arnemo and Soli 1995, Spelman et al 1997, Viggers and Lindenmayer 1995). In a study of European hedgehogs (*Erinsceus europaues*) by Arnemo and Soli (1995), all animals

immobilized with telazol were cateleptic and stiff during immobilization and spontaneous muscle contractions in the extremities were frequently seen. Animals in this study were also reactive to eartagging and sound. Contrary to the ketamine-medetomidine combination, ability to thermoregulate is maintained with this combination (Lariviere and Messier 1996*b*). Reversal with flumazenil markedly reduced recovery times for North American river otters (*Lontra Canadensis*; Spelman et al. 1997). In a study of recapture success conducted by Gehrt et al. (2001), raccoons immobilized with telazol had greater recapture rates than those immobilized with a combination of ketamine and acepromazine. They speculated that there may be different amnesic effects between these drugs, or induction with each drug may have differentially affected the psyche of the raccoons. This finding raises new questions regarding the use of anesthetics that need further investigation.

Induction and recovery

Induction time using isoflurane was relatively slow in our study, compared to injectable anesthetics. In all cases, a standard of 10 minutes was given before disturbance to ensure immobilization before handling. Belant (1995*b*) reported an extremely prolonged induction time using isoflurane in muskrats (18-24 minutes for adults). This difference may be due to a difference in induction method; an isoflurane soaked cotton ball was used rather than a vaporizer and oxygen. Higher levels of oxygen help to promote rapid induction (Dr. C. Morgan D.V.M., personal communication). Excitement levels also contribute to a prolonged or unsuccessful immobilization; a calmer animal will undergo a safer and smoother induction (Seal and Kreeger 1987).

Recovery was also rapid and smooth with no differences observed in the species in our study. In three instances, the animal became very active after only 2-3 minutes following the conclusion of isoflurane anesthesia. Although induction is more rapid using injectable anesthetics, recovery appears to be considerably shorter using inhaled isoflurane. Opossum recovery time (18.3 minutes, SD = 9.6) may have been artificially inflated because in 2002, one opossum feigned death ("played possum") for an extended period of time upon recovery. This individual was observed for over 30 minutes after anesthesia was turned off.

Other considerations

We believe it is important to consider that ketamine has recently been labeled a schedule II drug and has a high potential to be abused by humans. Ketamine is known to produce hallucinations and accidental oral ingestion or injection can produce immobilization in humans and hospitalization is required (Fowler 1995). Its use requires a US Drug Enforcement Agency permit and high security measures in the field. We considered the security risk to research personnel and equipment to be a deterring factor in our choice of anesthesia.

Biologists must consider several characteristics of anesthesia systems as they plan field experiments. Portable anesthesia systems are relatively expensive in comparison to injectable systems. In 1998, Kreeger et al. (1998) reported that their portable gas anesthesia system cost approximately $7000. However, the system that we used cost significantly less ($1400), suggesting that this method is becoming more accessible. Isoflurane is inexpensive ($60/250mL) and easy to handle. It comes in a liquid form and

is stored at room temperature. Isoflurane anesthesia mechanisms are bulky and heavy; we operated from a pick-up truck at roadside wetlands. However, Heath et al. (1996) used backpacks to transport this anesthetic equipment when study animals were trapped at a remote location. All-terrain vehicles could also be used when conditions permit.

Our anesthesia chamber allowed us to anesthetize mesopredators while previous studies used inhaled isoflurane for smaller mammals. The use of an isoflurane system as sole anesthesia is best suited for small to medium sized animals. Larger mammals will likely need to be immobilized using an injectable anesthetic and isoflurane can be used to prolong anesthesia as Heath et al. (1996) reported in Steller's sea lions.

In conclusion, isoflurane inhaled anesthesia produced smooth and uneventful induction and recovery in the mesopredators considered in this study. The additional time required to radio-mark animals did not affect recovery times. We suggest that in many instances, isoflurane should be chosen over the standard injectable anesthesia, ketamine. Although isoflurane requires more equipment than injectables, its ease of use and wide safety margins make it practical for use in a variety of field applications.

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Table 1. Mean times, in minutes (standard deviation), required to immobilize various species using an inhaled isoflurane anesthesia.

Species	n	Induction	Handling		Recovery	
			Collared	Uncollared	Collared	Uncollared
Raccoon	16	10.7 (1.1)	8.8 (3.4)	3.2 (1.1)	10.7 (4.0)	11.8 (2.5)
Striped Skunk	20	11.0 (2.4)	11.1 (4.2)	4.18 (2.4)	10.2 (5.1)	11.5 (2.1)
American Badger	2	17.5 (2.1)	20	10	14	10
Virginia Opossum	4	13.0 (8.1)	6	3.7 (4.7)	14	19.7 (11.2)
Mink	1	10	—	5	—	10

Figure 1. Field-suitable isoflurane gas anesthesia vaporizer used to immobilize mesopredators in the field (Rainwater Basin region, south-central Nebraska).

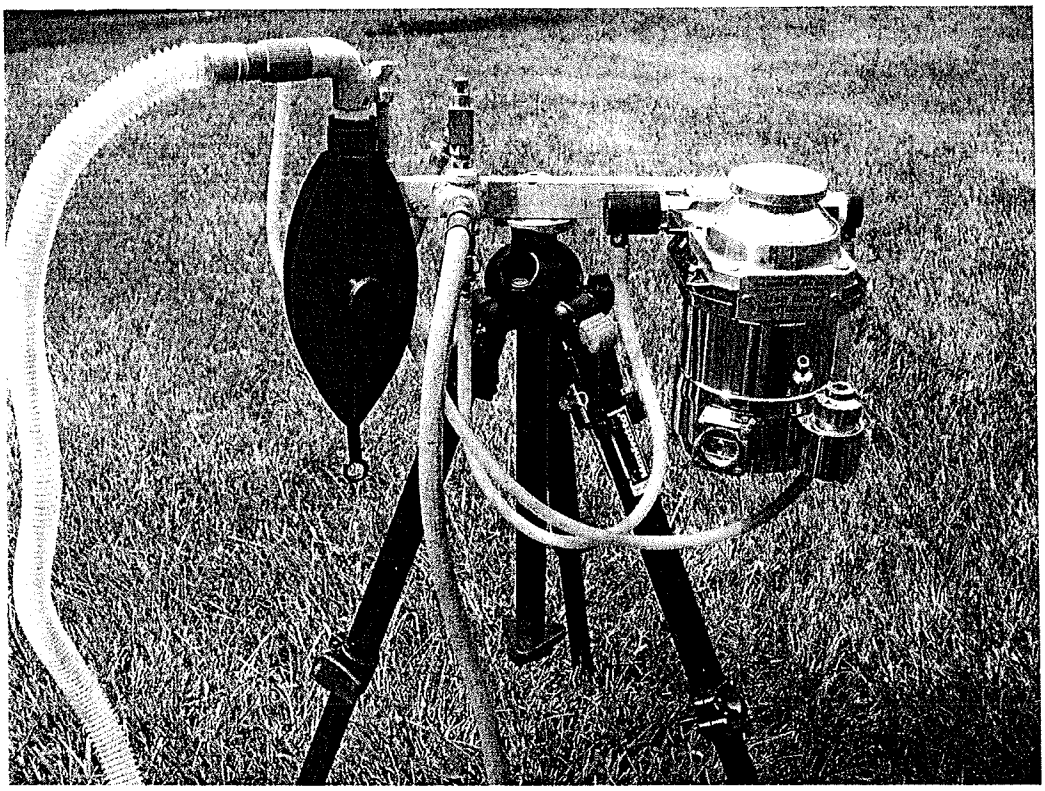

Figure 2. Isoflurane gas anesthesia chamber shown with plunger depressed.

A. The hose that administers the anesthesia

B. The window used to observe the animal while under anesthesia

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CHAPTER 2. Habitat selection and movements of mesopredators in Rainwater Basin wetlands of Nebraska

Abstract: The playa wetlands of the Rainwater Basin region of south-central Nebraska exist within a matrix of agricultural lands. Little is known about how mesopredators use the different habitats available. Our objectives were 1) to document movement patterns of dominant mesopredators within the landscape and 2) to determine habitat use versus availability (preferences) for these dominant mesopredators. We conducted this study from May through July of 2002 and 2003. We chose eleven wetlands as study sites based on proximity to each other, general size, and amount of untilled, upland habitat. We used GIS and visual observations to classify seven dominant habitat types within this study area (approx. 30,000 ha). We captured 43 and 35 individual mesopredators in 1345 and 1051 trap nights, during 2002 and 2003 respectively. Dominant species captured included raccoons (*Procyon lotor*), striped skunks (*Mephitis mephitis*), and Virginia opossums (*Didelphis virginiana*). We tracked 15 radio-marked individuals in 2002 (475 locations) and ten new individuals in 2003 (392 locations). Using estimated locations from telemetry data, we calculated home ranges using a fixed-kernel home range estimator (least squares cross validation smoothing). Overall, raccoons exhibited the longest movement distances as well as the largest home range sizes of the species studied. Both raccoons and skunks selected home ranges with more wetland area than was available in the surrounding landscape. To evaluate how mesopredators were using the landscape, we compared home ranges to 60 random landscapes. Raccoon home ranges contained lower edge densities, opossum home ranges contained more woodland edge, and skunk home ranges contained more wetland edge than the random landscape.

Simpson diversity indices for all mesopredators were not different than the random landscape. We used a compositional analysis to determine habitat preferences within mesopredator home ranges and a large landscape of available habitat (based on species-specific buffer around home range). Both raccoons and skunks exhibited a strong preference for wetland habitats whereas opossums tended to prefer woodland and grassland areas at both scales measured. All species considered tended to avoid farmsteads. Understanding predator response to differing habitats may be key in making effective management decisions.

INTRODUCTION

Mesopredators, mid-sized mammalian predators, can have a great impact on wetland bird nest survival (Greenwood 1981, Phillips et al. 2003). Wetland birds often exist in variable conditions because of habitat fragmentation, a diverse predator community, and variable weather conditions. Schneider (2001) suggested that species of concern in highly fragmented landscapes, such as songbirds in altered wetland ecosystems, would have much higher nest predation rates than those in less fragmented systems. Hoover et al. (1995) reported that small forest patches had high nest predation, compared to contiguous forests.

Patterns of nest predation may be driven by the diversity of predators in a region; different predators respond to landscape fragmentation at different scales (Stephens et al. 2003). Stephens et al. (2003) reported that nest survival may be best explained by considering the fragmented landscape and predator response to this landscape at a specifically defined scale, such as edge, patch, or landscape scales. Further, Chalfoun et

al. (2002) found that nest predator abundance and behavior was more influenced by landscape factors measured at a larger scale than at the local patch scale, as predator response was more variable at the local scale.

Wildlife biologists have studied the movements of mesopredators such as raccoons (*Procyon lotor*), striped skunks (*Mephitis mephitis*), and Virginia opossums (*Didelphis virginiana*) in a variety of different habitats and contexts. But, little is known about these species' movements and habitat use in the Rainwater Basin (RWB) region of south-central Nebraska. This region is similar to the Prairie Pothole region of North America in that agricultural development, including conversion of grasslands and wetlands to cropland and pasture, has resulted in a vast reduction in wetlands and quality wildlife habitat (Euliss et al. 1999, Sargeant et al. 1993). The lands of the Prairie Pothole region, like the RWB, are mostly privately owned with some federally owned areas, managed primarily for waterfowl production (Sargeant et al. 1993), as both of these areas are important to migratory birds (Euliss et al. 1999, LaGrange 1997). Unlike the RWB, the landscape of the Prairie Pothole region was largely the result of glaciation events during the Pleistocene. The wetlands of the pothole region are depressional wetlands caused by the uneven deposition of glacial till and the melting of large buried ice blocks (Euliss et al. 1999), while the RWB wetlands are wind-formed, clay-bottomed depressions filled by precipitation and run-off (LaGrange, 1997). The Prairie Pothole region (715,000 km^2) encompasses a considerably larger area than the RWB (11,000 km^2, Euliss et al. 1999, LaGrange 1997).

The RWB is named for the natural playa wetlands that dominate the landscape. The region is most often noted for their importance to migrating waterfowl, sandhill

cranes (*Grus canadensis*), and endangered whooping cranes (*Grus Americana*). Historically, there were nearly 4000 wetlands in this region but today fewer than 400 remaine as isolated patches within a highly fragmented agricultural landscape, (LaGrange 1997). These remaining wetlands vary in size, vegetation composition, relative amount of upland, and spatial characteristics for mesopredators (Gilbert 1989). Thus, habitat quality varies across the landscape. To promote sustainable wetland bird populations, it is critical for habitat managers to establish how mesopredators in this region use the habitats available. Habitat use information can also guide land acquisition decisions, as portions of the landscape are restored.

A landscape in which resources are heterogeneously distributed will inevitably have an influence on the distribution of animals inhabiting the region. An animal's preference for a particular habitat will also depend on the current requirements of that animal, such as food availability, shelter, or the need to search for mates (Matthiopoulos 2003). As these requirements are expected to vary among species, years, and individuals, we expect habitat preference to vary in similar ways. Typically, an animal will select a landscape that offers frequent encounters with these resources, as they are necessary for survival (Pedlar et al. 1997).

Raccoons are often considered 'ecological opportunists.' They are incredibly adaptable and can be found in a variety of habitats (MacClintock 2002), but Allen (1987) identified wetlands as a key component of a raccoon's habitat. Skunks, like raccoons, tend to exhibit a preference for wetland areas. For example, Phillips et al. (2003) reported that skunks strongly selected for wetland edges that were surrounded by areas of agriculture in North Dakota. This becomes an important point when managing for

waterfowl and songbird populations that rely on wetlands, as skunks are known nest-predators (Nack 2002, Phillips et al. 2003, Sargeant et al. 1993).

Our goal was to determine how mesopredators, as represented by raccoons and striped skunks, used the landscape in Nebraska's RWB. We were especially interested in the role that wetlands played in mesopredator movement dynamics. Because wetlands can serve as food sources for mesopredators, we expected home ranges to be smaller and more localized when encompassing these areas and larger and more spread out when food resources were scarce. We predicted that mesopredators in the RWB would concentrate their activities primarily in wetland areas, and could therefore have an impact on nesting birds in these habitats.

Our objectives in conducting this study were 1) to document movement patterns of dominant mesopredators within the landscape, 2) to determine habitat use versus availability (preferences) for these dominant mesopredators.

STUDY AREA

Our study was conducted from May to July during 2002 and 2003 in the RWB of south-central Nebraska . Our sampling period coincided with the songbird breeding season, as this project was part of a concurrent study on nest survival.

The US Fish and Wildlife Service and the Nebraska Game and Parks Commission currently manage approximately 12,000 hectares of wetlands and associated upland habitat (LaGrange 1997). Although many privately owned wetlands have little associated upland habitat (untilled grassland habitat bordering the wetland on at least one side), restoration projects on some of these publicly owned wetlands have resulted in significant

improvements in the surrounding landscape. Nonetheless, the boundaries of a wetland's associated habitat with the surrounding agricultural habitat are quite abrupt.

Our study area (~30,000 ha) was located in Clay County, in south-central Nebraska, just south east of Clay Center, Nebraska (40°31′37″N, 98°03′13″W, Figure 1). We chose eleven wetlands as study sites based on proximity to each other, general size, and amount of untilled, upland habitat. We included six public (5 federal Waterfowl Production Areas and 1 state Wildlife Management Area) and five private wetlands in this study. The landscape of our study area was dominated by agriculture, including corn and soybeans, interspersed with wetlands and pastureland. Average precipitation for this region during May – July from 1971 to 2004 was 32.5 cm. However, precipitation during this time in 2002 and 2003 was lower than average (22.17 cm and 30.35 cm, respectively, High Plains Regional Climate Center, University of Nebraska-Lincoln).

METHODS

Target species

We monitored study sites for all species of mesopredators; however raccoons and striped skunks were our primary target species because of local abundance and ability to carry a radio transmitter. Other mesopredators known to inhabit this region include Virginia opossums, American badgers (*Taxidea taxus*), mink (*Mustela vison*), red fox (*Vulpes vulpes*), coyote (*Canis latrans*), and feral cats (*Felis catus*).

Field methods

We conducted live trapping twice on each wetland for a 4-5 day period each year using live traps. To maximize captures, we chose trap sites within each wetland based on presence of animal tracks or other signs of mesopredators using the specific area (Chamberlain and Leopold 2002, Sargeant et al. 1993). We baited the traps primarily with sardines or anise oil, but we occasionally used chicken livers or fish oil (M. Phillips, Northern Prairie Wildlife Research Center, F. Pogmore USDA, and R. Bischof NGPC, personal communications). Coordinates of each trap site were recorded using a WAAS enhanced, handheld GPS receiver. Traps were set between 1600 and 2000 and checked between 0700 and 1000. We weighed, sexed, and ear tagged all captured animals, and we radio-marked a sub-sample of raccoons, skunks, and opossums using 30g radio collars (model MI-2, Holohil Systems Ltd, Carp, Ontario, Canada). We anesthetized captured animals with inhaled isoflurane (MWI Veterinary Supply Co., Nampa, ID) using a portable anesthesia machine (R.B. Heath, DVM, Seven Seven Anesthesia, Fort Collins, CO) to provide anesthesia at the capture location. Animals were released at their capture location usually within 30 minutes.

We conducted radio telemetry between approximately 2000 and 0500 at least four nights per week to document movement and habitat use. Individual animals were located as many times as possible throughout the night; generally, one to three locations per night were recorded using a six-element, Yagi-style, truck-mounted antenna. For each recorded location, three bearings were taken within approximately ten minutes to reduce location error. Successive locations for each individual were separated by at least 60 minutes in order to ensure independence (Gehrt and Fritzell 1998).

Statistical analysis

We used program LOAS © (Ecological Software Solutions, Sacramento CA, USA 1999) to estimate animal locations from bearings collected in the field. We calculated intra-nocturnal movement (the total distance moved between locations taken during one sampling night) and inter-nocturnal movement (the distance moved from the last location taken of the sampling night to the first location taken the next sampling night).

We used a fixed kernel estimator (Kernohan et al. 2001, Seaman et al. 1999) to calculate home ranges using the Home Range Extension (Centre for Northern Forest Ecosystem Research, Ontario Ministry of Natural Resources) in ArcView 3.2 (ESRI, Redlands CA, USA). We used least-squares cross validation to calculate our smoothing bandwidth (Seaman and Powell 1996). We only calculated home ranges for animals with >20 independent locations (Phillips et al. 2003), as kernel based methods tend to over-estimate home range size when using small sample sizes (Seaman and Powell 1996).

We prepared a land cover GIS layer for our study area by modifying the 2002 National Agricultural Statistics Service (NASS) cropland data layer. We used the National Wetland Inventory (US Fish and Wildlife Service) coverage to delineate wetland boundaries, and we added farmsteads and wooded areas from our observations and aerial photographs. We collected field observations during 2003 to note changes in crop rotations. The GIS data were stored, edited, and analyzed using either ArcView 3.2 or ArcGis 8.0 (ESRI, Redlands CA, USA). We identified 7 dominant habitat classifications to include in our analyses: 1) corn, 2) soybeans and other row crops, 3) grassland/hay/pasture, 4) woodland, 5) farmsteads, 6) wetlands, and 7) roads and associated ditch habitats. For each radio-marked individual, we used GIS to delineate the

habitat layer to include only those habitats within the animal's home range. We considered this landscape area to be the individual's utilization distribution (Kernohan et al. 2001). To compare habitat composition in the utilized landscape with the available landscape, we created a buffer around each home range (Figure 2). We used a species-specific buffer distance, based on the distance that our data indicated the species could move over a period of 2 days (raccoon = 2 km; skunk = 1.4 km; opossum = 1.2 km). By defining available habitat as an extension of an individual's home range, we alleviated the problems associated with an arbitrarily defined habitat availability (Aebischer et al. 1993). To evaluate differences among species, utilized and available landscapes, and dominant habitat types, we determined the proportion of animal locations in each habitat type. We used an arcsine transformation to determine 95% confidence intervals as the data were based on percent of the landscape in each habitat type. We used a linear regression to test the hypothesis that mesopredator home range size decreased as area of wetland within the home range increased.

We used SAS (GLM procedure, SAS Institute 2000; J. Bittle, USFWS personal communication) to perform a compositional analysis to estimate habitat preference and a multivariate analysis of variance model using Wilks' Λ to test for differences in sex and year for each species based on habitat use versus availability (Aebischer et al. 1993). Most land-cover types were not modified throughout the duration of the study. However, due to yearly crop rotations, relative amounts and arrangements of corn, soybeans and other row crops, and grassland/hay/pasture habitat types did fluctuate. Thus, we based all habitat preference analyses for a particular animal on the respective year in which telemetry data were collected for that individual. Habitat preference was calculated as

the log-ratio of habitat use (percent of radio-locations in each habitat) to habitat availability (percent of individual landscape covered by each habitat). We determined habitat availability in two ways: 1) proportion of available habitat within an individual's home range (utilized habitat) and 2) proportion of habitat potentially available to the individual, as defined above (additional buffer zone around the home range). We compared log-ratios (proportion of habitat use/habitat availability) of the seven habitat types to evaluate selection and avoidance tendencies for raccoons and skunks (Table 3). We tested for a significant preference or avoidance for a habitat (used in greater or lesser proportion than its abundance) by considering the 95% confidence interval (Colegrave and Ruxton 2002, Johnson 1999, Steidl et al. 1997); significant log-ratios were those whose confidence interval did not include 0 (equal use and availability). Positive log-ratio values indicated a preference for a particular habitat type (i.e. higher use than available). We evaluated *t* values to detect significant differences among ranked habitat types at $\alpha \leq 0.05$.

We also created 60 random landscapes, approximately twice the number of home ranges in our analyses, by randomly plotting points in GIS across our study area landscape. We then created a circle polygon with a 950 m radius (area = 283 ha; similar to the average sizes of raccoon and skunk home ranges in our study) around each random point and similarly clipped the habitat layer to create an artificial home range. We used FRAGSTATS version 3 (University of Massachusetts, Amherst) to compare these random landscapes to actual home ranges to test the prediction that mesopredators were selecting preferred habitats. The landscape statistics that we generated with FRAGSTATS included edge density (total edge per unit area), landscape shape index

(measure of patch aggregation), amount of wetland and woodland edge, and amount of wetland edge along all other habitat types. We also determined a Simpson diversity index of landscape composition for both mesopredator home ranges and random landscapes.

RESULTS

Captures and radio-telemetry

We captured 43 and 35 individual mesopredators in 1345 and 1051 trap nights during 2002 and 2003 respectively. Our sample included raccoons (2002:10, 2003:8), skunks (2002:12, 2003:11), Virginia opossums (2002:17, 2003:14), and others (American badger, mink, and feral cats). In 2002, we radio-marked a sub-sample of 15 individuals, including six raccoons, five skunks, and four opossums and determined 475 telemetry locations (41% raccoon, 37% skunk, and 21% opossum). Although opossums were our most commonly captured mesopredator, we did not radio-mark them in 2003 because our 2002 telemetry indicated that opossums were not selecting wetland areas as foraging sites. In 2003, we radio-marked ten new individuals: five raccoons, four skunks, and one badger. We also relocated four live animals that were radio-marked in 2002 including one raccoon, two skunks, and one opossum. We determined 392 telemetry locations (44% raccoon, 42% skunk, 11% opossum, and 3% badger) during the 2003 field season.

Movement and home ranges

Overall, raccoons exhibited the longest movement distances of the three species we considered. Inter- and intra-nocturnal movements for raccoons averaged 983.6 m (*SD*

= 423.9) and 671.4 m (SD = 378.5), striped skunks averaged 653.3 m (SD = 211.8) and 564.1 m (SD = 232.5), and opossums averaged 584.7 m (SD = 246.3) and 606.8 m (SD = 294.7, Table 1). Home ranges also reflected the raccoons tendency to cover larger expanses of the landscape than skunks or opossums. The average 95% home range for raccoons, was 311.5 ha (SD = 259.9) compared to 264.9 ha (SD = 110.8) for skunks and 94.6 ha (SD = 67.1) for opossums (Table 1).

Habitats within the home ranges for both raccoons and skunks were different from the surrounding landscape (Table 2). We pooled data across sex and year, as these effects were not significant ($P > 0.05$). Both species selected home ranges with more wetland area than was available in the surrounding landscape, as expected (Table 2 and Table 3). Both raccoon ($R^2 = 0.32$, $P = 0.15$) and skunk ($R^2 = 0.31$, $P = 0.16$) home ranges tended to decreases in size as area of wetlands within their home ranges increased. Raccoons selected home ranges with fewer farmsteads than available, and skunks showed a similar trend. Both species exhibited trends of selecting less planted cropland than was available with skunks significantly selecting home ranges with less corn than was available (Tables 2 and 3).

Raccoon home ranges contained less wetland-farmstead edge and lower edge densities than the random landscape (Table 4). Skunk home ranges also contained less wetland-farmstead edge but also contained more wetland edge than the random landscape (Table 4). Opossum home ranges contained more woodland edge but less wetland-corn, wetland-grassland, wetland-woodland, and wetland-farmstead edges than the random landscape (Table 4). Simpson diversity indices of home range composition for all

mesopredators were not different than the composition of the random landscape (Table 4).

Habitat use and preference

Our study landscape was dominated by agriculture (59% of area), including corn, soybeans, and other row crops. The area also included grassland, hay, and pasture (9% of area), wetlands (17% of area), woodlands (2% of area), roads and associated ditch habitats (13% of area), and farmsteads (<1% of area).

Multivariate analyses of variance revealed no overall year or sex effect in habitat use versus availability for both raccoons ($n = 11$; home range, year: $F_{6,3} = 1.45$, $P = 0.41$, sex: $F_{6,3} = 3.74$, $P = 0.15$; available habitat, year: $F_{6,3} = 1.60$, $P = 0.38$, sex: $F_{6,3} = 5.25$, $P = 0.10$) and skunks ($n = 10$; home range, year: $F_{6,2} = 0.13$, $P = 0.98$, sex: $F_{6,2} = 6.11$, $P = 0.15$; available habitat, year: $F_{6,2} = 0.11$, $P = 0.98$, sex: $F_{6,2} = 3.49$, $P = 0.24$) at the two landscape levels examined. Rank of habitat preference within the home range for raccoons was corn > wetland > soybeans and other row crops > roads > woodland > grassland/hay/pasture > farmsteads. Raccoons exhibited a preference of corn over farmsteads ($P = 0.01$). They also showed a preference for corn over soybeans and other row crops ($P = 0.06$), as well as soybeans and other row crops over farmsteads ($P = 0.07$). Rank of habitat preference within the available habitat (home range and 2 km buffer) for raccoons was wetlands > corn > roads > grassland/hay/pasture > soybeans and other row crops > woodlands > farmsteads. Preferences were determined for corn ($P < 0.001$), grassland/hay/pasture ($P = 0.02$), wetlands ($P = 0.02$), and roads ($P = 0.03$) over farmsteads. Again, raccoons tended to prefer corn over soybeans and other row crops ($P = 0.07$) and soybeans and other row crops over farmsteads ($P = 0.05$).

Rank of habitat preference within the home range for skunks ($n = 10$) was woodland > wetland > corn > soybeans and other row crops > grassland/hay/pasture > roads > farmsteads. Skunks preferred corn ($P < 0.001$), soybeans and other row crops ($P < 0.001$), woodland ($P < 0.001$), and wetland ($P < 0.001$) over farmsteads, and woodlands over grassland/hay/pasture ($P = 0.04$). Skunks also showed a preference for wetlands ($P = 0.06$), soybeans and other row crops ($P = 0.07$), corn ($P = 0.08$), and woodlands ($P = 0.09$) over roads. Rank of habitat use preference within the available habitat (home range and 1.4 km buffer) for skunks was woodland > wetland > soybeans and other row crops > corn > grassland/hay/pasture > road > farmsteads. Again, a preference for corn ($P < 0.001$), soybeans and other row crops ($P < 0.001$), woodland ($P = 0.001$), and wetland ($P < 0.001$) over farmsteads was exhibited within the larger landscape. Skunks also preferred woodland ($P = 0.04$) over grassland/hay/pasture, and wetlands over corn ($P = 0.05$), soybeans and other row crops ($P = 0.01$), and farmsteads ($P < 0.001$); and woodlands ($P = 0.05$) and soybeans and other row crops ($P = 0.08$) over roads and wetlands over grassland ($P = 0.08$).

We relocated only one opossum and did not radio-mark any additional opossums in 2003. Therefore, we could not perform a multivariate analysis of variance to test for sex and year differences for this species. Rank of habitat preference within the home range for opossums ($n = 4$) was woodland > grassland/hay/pasture > corn > soybeans and other row crops > roads > wetlands > farmsteads. Opossums preferred woodland over both row and other crops ($P = 0.04$) and grassland/hay/pasture ($P = 0.01$). Opossums also preferred woodland over both corn ($P = 0.08$) and wetland ($P = 0.08$). Ranks of habitat preference within the available habitat (home range and 1.2 km buffer) was

woodland > road > grassland/hay/pasture > corn > soybeans and other row crops > farmsteads > wetlands. Again, opossums showed a preference for woodland over soybeans and other row crops ($P = 0.01$) as well as grassland/hay/pasture ($P = 0.04$). Opossums also tended to prefer woodland over both corn ($P = 0.06$) and farmsteads ($P = 0.10$).

DISCUSSION

Mesopredator movements and home range areas tend to vary according to sex, age, habitat, and food availability (Kuehl and Clark 2002, Messick 1987, Sanderson 1987, Seidensticker et al. 1987). Inter-nocturnal movement of raccoons was considerably larger than that of skunks or opossums. Seidensticker et al. (1987) observed that raccoons made long, direct-line movements from denning sites to foraging sites, with individuals moving over 2,000 meters in some cases. In 2002, our data show similar movement trends in raccoons and skunks, based on sex, with males traveling farther than females, on average. However, in 2003 female raccoons moved farther than males and there was essentially no difference in distances moved between male and female skunks. In 2002, female opossums moved considerably farther than males. Seidensticker et al. (1987) reported an instance where a female opossum with pouch young traveled 1,850 meters during one night. Because female opossums carry their young in a pouch, the motivation and ability to travel great distances to avoid a potential predation threat or to search for better foraging opportunities in order to increase the survival of their young, may explain these long distance movements. We only radio tracked adults so we cannot attribute any differences in movement or home range sizes based on age.

In 2002, males of all species exhibited larger home ranges than females, as expected. For skunks, trends in our data (especially in 2003) were similar to Greenwood et al. (1985) in which male skunks had considerably larger home ranges than females. Our data did not allow sex-specific comparisons for raccoons and opossums in 2003. This recurring trend of males traveling farther than females may be attributable to late breeding attempts by the males or higher energetic needs because of a larger body mass (Greenwood et al. 1985, Lariviere and Messier 1998*b*). Gehrt and Fritzell (1997) and Sanderson (1987) reported that female raccoons reduced the size of their home ranges in summer, presumably as a result of caring for young, which could also explain the smaller home ranges of female opossums and skunks as well. Other studies have reported home range sizes for raccoons between 40 and 2600 ha (Chamberlain and Leopold 2002, Sanderson 1987, Sargeant et al. 1993) and for skunks between 87 and 688 ha (Greenwood et al. 1985, Sargeant et al. 1993). The smaller home range sizes are generally attributed to individuals in high density populations or in areas where food resources are plentiful. Relatively low mesopredator population densities in the RWB are reflected in the moderately sized home ranges (raccoons: 312 ha, skunks: 265 ha) exhibited by all species.

As expected, raccoons and skunks showed a strong preference for wetlands in the RWB. Raccoons are well-known for concentrating their activities near areas of water as much of their diet is associated with aquatic resources (Gehrt and Fritzell 1998, MacClintock 2002). A suitable den for a raccoon is generally located within 0.4 kilometers of water (MacClintock 2002). Dijak and Thompson (2000) reported that agricultural landscapes with available sources of water can support high densities of

raccoons. Lariviere and Messier (2000) also noted a high use of wetlands by skunks. Lariviere and Messier (1998*a*) determined that skunks preferentially choose resting sites and natal dens in wetland areas. This is likely a reflection of their tendency to rest near food sources, though cropland was highly available but never used for natal dens in their study. However, wetlands that were surrounded by planted cover were not strongly selected by skunks in studies conducted by Lariviere and Messier (1998*a*) and Phillips et al. (2003), suggesting a possible avoidance of grassland habitats. Opossums appeared to choose all other habitat types over wetlands, with the only exception being farmsteads at the home range level. In a Virginia study, opossums tended to be associated with shrubby thickets and wet areas with open canopy during the summer (Seidensticker et al. 1987). Allen (1987) correlated water permanency in a wetland habitat to furbearer habitat quality, the assumption being that wetland drainage reduces water permanency, which reduces prey availability.

Similar to the study conducted by Lariviere and Messier (2000) in Saskatchewan, Canada, habitat selection patterns did not differ between male and female skunks or raccoons. Home ranges for both skunks and raccoons in our study centered around wetlands, corn, soybeans and other row crops, and woodlands while showing an apparent avoidance of farmsteads and a weak negative preference for grassland/hay/pasture. The preference for corn is not surprising because raccoons and skunks use corn in their diets, and waste corn that has been left in the fields from the previous year is readily available in the RWB. Greenwood (1981) collected raccoon scats from April – July in North Dakota and reported that cereal grains including corn were staples in raccoon diets and MacClintock (2002) noted cornfields as a favorite feeding site for raccoons as well.

Lariviere and Messier (2000) determined that skunks had a strong avoidance of grassland, in their study area, likely due to low abundance of typical food items such as insects and small mammals, in their study area so it is also not surprising to note a similar trend in the RWB.

Farmsteads may provide a variety of food sources, as well as shelter opportunities for both raccoons and skunks; so, we did not expect to find that raccoons and skunks avoided farmsteads. Sanderson (1987) reported that a typical raccoon den may include piles of rubbish, brush, and lumber, and a variety of artificial structures located in and around farmsteads. Female skunks in Lariviere and Messier (1998*a*) showed a preference for farmsteads. They used abandoned buildings for natal dens and resting sites and tended to occupy buildings with minimal human activities, such as storage buildings for equipment and grain (Lariviere and Messier 1998*a*). However, another study conducted by Lariviere and Messier (2000) produced the opposite results; farmsteads were rarely used by skunks. We did not differentiate between abandoned and inhabited farmsteads in this study. But, we observed that most farmsteads were occupied in this highly productive agricultural region, which may explain the avoidance of farmsteads that we documented.

We captured fewer mesopredators than we anticipated. It must be noted, however, that our low capture rates of all mesopredators studied could possibly be an artifact of the time of year this research was conducted, rather than (or as well as) simply low densities. In the summer, food supplies are most readily available; mesopredators can afford to be picky about what they choose to eat and may choose not to enter a trap. Gehrt and Fritzell (1996) reported higher recapture rates for raccoons in the winter and

spring, when food supplies were scarce, when compared to summer and fall seasons during their mark-recapture study in Texas. Gehrt and Fritzell (1996) also noted that male raccoons were captured consistently more often than female raccoons in all seasons. They suggested this was a reflection of an increased vulnerability of males, because of their tendency to move greater distances than females, especially during the mating season when female movement is restricted by rearing young. Our results did not reflect this; we captured considerably more adult females than males during both sampling seasons. Lariviere and Messier (1998*b*) and Greenwood et al. (1985) suggest that female-biased sex ratios could be the result of spring dispersal and higher mortality of males. Because we spread our resources across multiple species, sample sizes may have affected our ability to determine sex and year differences from our limited amount of movement and home range data. We were unable to estimate population sizes or capture rates for the mesopredators in the RWB due to a lack of recaptures.

Our study did not consider the availability of prey items, including birds and bird eggs, as well as small mammals, insects, and aquatic invertebrates. These factors are likely a driving force behind the habitat preferences of mesopredators that we documented, and we encourage further investigation.

Management implications

Management decisions in the RWB are usually made to benefit waterfowl during spring migration. But the region also serves as important habitat for nesting waterfowl and songbirds. Land management and land acquisition decisions can be made more effective by incorporating information on potential predators of birds and bird nests.

Mesopredators are well known opportunistic feeders and have the ability to move great distances in a short amount of time; therefore, they have the potential to negatively effect nesting birds. Raccoons and skunks tended to avoid grassland areas in our study. Nack (2002), Phillips et al. (2003), and Stephens et al. (2003) suggested that increasing areas of grassland, hay and pasture lands surrounding wetlands, critical habitat for waterfowl and nesting birds, could potentially reduce predator impact on these populations. In our study, skunks and opossums exhibited strong preferences for woodland areas. Although not as apparent in our study, raccoons are also well known to use wooded areas for food, denning, and resting sites (Allen 1987, MacClintock 2002, Pedlar et al. 1997). Therefore, removal of woody vegetation immediately surrounding wetlands may also enhance bird survival. Home ranges of both raccoons and skunks tended to be smaller as total area of wetlands within the home range increased; animals in a more natural landscape (i.e., more wetlands) had smaller home ranges than animals existing in more altered parts of the landscape (i.e., more human disturbance).

Mesopredators in the RWB used a landscape composed of a mix of wetlands, agricultural, and wooded areas. Based on our data, management decisions made to improve songbird survival should focus on increasing the area of grassland immediately adjacent to wetlands and increasing the amount of open water within the wetlands. Biologists could greatly improve the effectiveness of long term management efforts by considering the response of a predator population (Phillips et al. 2003).

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Table 1. Average distances moved (meters) and 50% and 95% home range estimates (hectares, standard deviation) for raccoons, striped skunks, and Virginia opossums in the Rainwater Basin region of south-central Nebraska. See text for definition of inter- and intra-nocturnal movement.

				Movement (m)	Movement (m)	Kernel-estimated home range (ha)		
Species	n	Sex	Year	Inter-nocturnal	Intra-nocturnal	50%	95%	n-points
Raccoon	1	M	2002	1319.51	1550.84	76.30	341.78	47
Raccoon	5	F	2002	789.36 (543.23)	453.00 (165.56)	*37.487 (48.10)	*174.48 (214.69)	150
Raccoon	6	pooled	2002	877.72 (531.91)	635.97 (472.02)	*45.23 (45.13)	*207.94 (200.42)	197
Raccoon	2	M	2003	971.47 (245.88)	670.90 (79.26)	–	–	22
Raccoon	4	F	2003	1148.44 (329.40)	724.71 (381.58)	103.94 (61.31)	483.97 (290.93)	136
Raccoon	6	pooled	2003	1089.45 (292.48)	706.77 (298.98)	103.94 (61.31)	483.97 (290.93)	58
Raccoon	12	pooled	pooled	983.59 (423.93)	671.37 (378.51)	*67.25 (56.22)	*311.45 (259.89)	355
Skunk	3	M	2002	586.13 (85.80)	612.69 (359.27)	70.26 (29.22)	328.13 (125.20)	102
Skunk	2	F	2002	433.17 (40.21)	419.37 (245.96)	67.38 (30.02)	302.08 (141.17)	74
Skunk	5	pooled	2002	524.95 (105.38)	535.36 (301.45)	58.99 (26.66)	274.99 (115.89)	176

Skunk	3	M	2003	714.64 (202.58)	740.20 (121.61)	*60.58 (30.00)	*270.88 (166.69)	91
Skunk	4	F	2003	767.80 (271.26)	*435.73 (22.61)	**202.65	**48.81	69
Skunk	7	pooled	2003	745.02 (226.45)	587.97 (184.20)	**248.14 (124.28)	**56.65 (22.27)	160
Skunk	12	pooled	pooled	653.32 (211.78)	564.06 (232.53)	**58.11 (23.44)	**264.92 (110.82)	336
Opossum	1	M	2002	318.50	238.45	2.49	14.54	39
Opossum	2	F	2002	766.40 (188.77)	841.90 (63.49)	27.33 (14.67)	125.47 (69.69)	61
Opossum	3	pooled	2002	617.10 (291.01)	640.75 (351.28)	19.05 (17.70)	88.49 (80.81)	100
Opossum	–	M	2003	–	–	–	–	–
Opossum	1	F	2003	487.57	505.052	28.53	113.03	44
Opossum	1	pooled	2003	487.57	505.052	28.53	113.03	44
Opossum	4	pooled	pooled	584.72 (246.28)	606.83 (294.74)	21.42 (15.21)	94.63 (67.11)	144

*One asterisk (*) denotes removal of one individual from n and double asterisks (**) denote removal of three individuals from n because of insufficient sample size

Table 2. Average proportion (95% confidence interval)[1] of seven habitat classes in utilized habitat (home range) and available habitat (defined by species-specific buffer around home range: raccoon = 2 km, skunk = 1.4 km) for raccoons (n = 11) and skunks (n = 10) in the Rainwater Basin region, Clay County, Nebraska during 2002 and 2003.

	Raccoons		Skunks		Random Landscape
Habitat	Utilized	Available	Utilized	Available	
Corn	0.39 (0.11-0.71)	0.42 (0.29-0.56)	0.32 (0.05-0.66)	0.43 (0.29-0.57)	0.43 (0.13-0.75)
Row and Other Crops	0.24 (0.01-0.60)	0.32 (0.17-0.49)	0.30 (0.07-0.58)	0.31 (0.18-0.45)	0.42 (0.14-0.73)
Grassland/Hay/Pasture	0.12 (0.00-0.37)	0.10 (0.00-0.28)	0.14 (0.00-0.40)	0.10 (0.05-0.16)	0.09 (0.00-0.29)
Woodland	0.02 (0.00-0.07)	0.03 (0.01-0.05)	0.03 (0.00-0.09)	0.02 (0.01-0.03)	0.01 (0.00-0.38)
Farmstead	<0.01 (0.00-0.01)	0.01 (0.00-0.01)	<0.01 (0.00-0.01)	0.01 (0.00-0.01)	<0.01 (0.00-0.01)
Wetland	0.20 (0.01-0.68)	0.09 (0.04-0.16)	0.19 (0.02-0.44)	0.12 (0.05-0.20)	0.04 (0.00-0.13)
Road	0.03 (0.01-0.05)	0.02 (0.02-0.03)	0.02 (0.010.03)	0.02 (0.02-0.03)	0.01 (0.00-0.02)

[1]95% Confidence intervals constructed using arcsine transformations

Table 3. Log-ratios (proportion habitat use/habitat availability) and 95% confidence interval for 7 habitat types used in the Rainwater Basin region, Clay County, Nebraska by radio-marked raccoons (2002:6, 2003:5) and skunks (2002:5, 2003:5) in each animal's home range and available landscape (home range and surrounding species-specific buffer area).

Raccoon	Home Range		Available Landscape	
Habitat	2002	2003	2002	2003
Corn	-0.100 (0.195)	-0.078 (0.253)	-0.344 (0.563)	-0.121 (0.151)
Row and Other Crops	-0.874 (1.228)	-0.680 (0.268)[a]	-1.697 (2.516)	-1.021 (0.314)[a]
Grassland/Hay/Pasture	-1.449 (1.835)	-1.130 (2.626)	-2.331 (3.058)	-0.049 (0.908)
Woodland	-1.805 (2.948)	-0.272 (2.576)	-2.332 (3.058)	-0.401 (2.741)
Farmstead	-1.973 (0.861)[a]	-2.221 (2.610)	-3.955 (0.308)[a]	-2.546 (2.676)
Wetland	0.409 (0.303)[a]	-1.255 (2.790)	1.135 (0.501)a	-0.916 (2.827)
Road	-2.606 (2.413)[a]	0.984 (0.773)[a]	-2.488 (2.579)	0.987 (0.631)[a]

[a]95% Confidence interval indicated preference or avoidance

Skunk	Home Range		Available Landscape	
Habitat	2002	2003	2002	2003
Corn	-0.047 (0.373)	-0.307 (0.560)	-0.449 (0.538)	-0.705 (1.033)
Row and Other Crops	-0.155 (0.159)	-0.364 (0.202)[a]	-0.166 (0.281)	-0.529 (0.319)[a]
Grassland/Hay/Pasture	-1.422 (2.284)	-2.604 (3.604)	-1.789 (2.431)	-2.124 (3.896)
Woodland	1.190 (0.589)[a]	-0.416 (2.542)	1.027 (0.726)[a]	-0.025 (2.617)
Farmstead	-2.913 (1.917)[a]	-2.289 (0.569)[a]	-2.809 (2.074)[a]	-3.775 (0.536)[a]
Wetland	0.007 (0.275)	-0.226 (0.598)	0.620 (0.520)[a]	-0.010 (0.560)
Road	-3.262 (2.836)[a]	-1.545 (3.074)	-3.195 (2.611)[a]	-1.557 (3.100)

[a]95% Confidence interval indicated preference or avoidance

Table 4. Landscape and edge characteristics of mesopredator home ranges and random landscapes with 95% confidence intervals, in Rainwater Basin wetlands of Nebraska.

Parameter	Raccoon	Skunk	Opossum	Random
Edge Density[1]	103.6 (15.1)	107.3 (8.8)	125.9 (20.2)	124.1 (5.6)
Tree Edge[2]	13.7 (4.4)	13.9 (3.8)	17.9 (0.6)	12.5 (2.4)
Wetland Edge[2]	17.9 (6.1)	23.2 (6.2)	12.9 (7.2)	15.2 (2.0)
Wetland-Corn Edge[2]	98.1 (73.2)	69.3 (40.0)	9.0 (9.1)	34.1 (6.9)
Wetland-Soybean Edge[2]	63.8 (52.0)	61.5 (37.2)	22.0 (29.0)	42.0 (9.3)
Wetland-Grassland Edge[2]	67.6 (38.9)	58.3 (22.7)	20.0 (15.4)	45.0 (7.2)
Wetland-Woodland Edge[2]	27.8 (12.3)	12.6 (7.8)	1.5 (2.3)	15.9 (5.4)
Wetland-Farmstead Edge[2]	0.2 (0.3)	0.1 (0.2)	0.0 (0.0)	1.0 (0.5)
Wetland-Road Edge[2]	21.3 (13.0)	13.6 (8.3)	0.3 (0.5)	7.3 (3.2)
Landscape Shape Index[3]	7.1 (1.2)	6.4 (0.6)	6.4 (0.9)	6.3 (0.2)
Simpson Diversity Index	0.7 (0.1)	0.7 (<0.1)	0.7 (<0.1)	0.6 (<0.1)

[1]Edge Density: Total edge length (m) of a habitat patch divided by total landscape area (m^2). Reported on a per unit area basis to facilitate comparison among landscapes of varying sizes. (FRAGSTATS, University of Massachusetts, Amherst).

[2]units are number of 30-m pixel widths

[3]Landscape Shape Index: Total edge length of a habitat type (as number of 30-m cell surfaces), divided by the minimum length of habitat edge possible for a maximally clumped, single compact patch (number of 30-m cell surfaces). As LSI increases, patches become increasingly separated (FRAGSTATS, University of Massachusetts, Amherst).

Figure 1. Our study area was a portion of the Rainwater Basin region, located in south-central Nebraska.

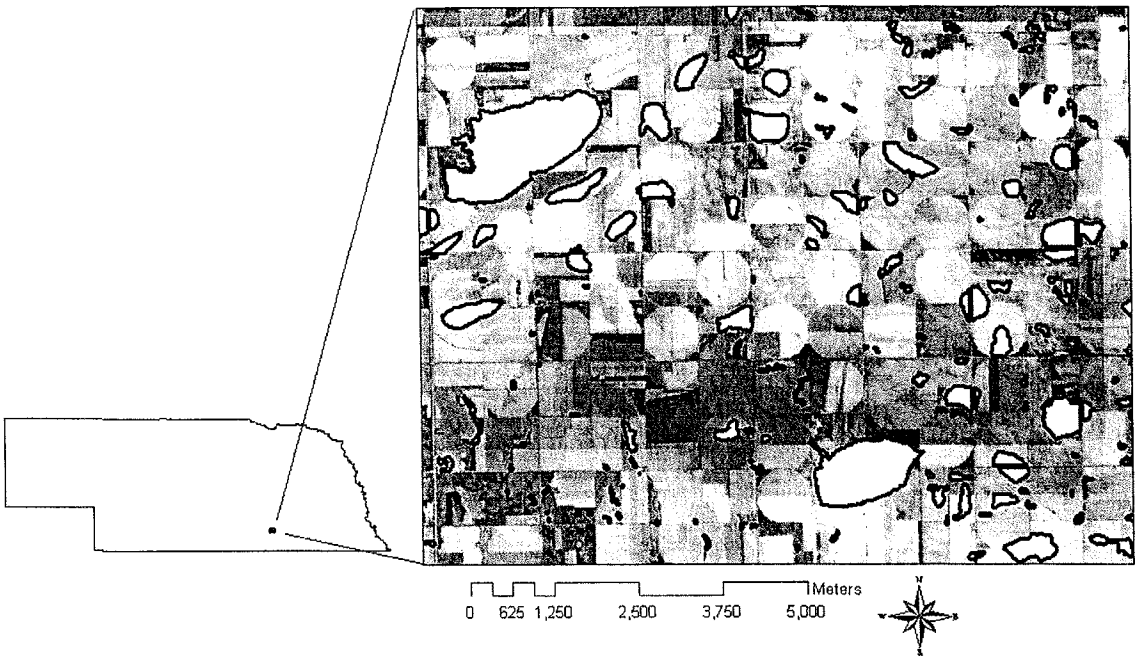
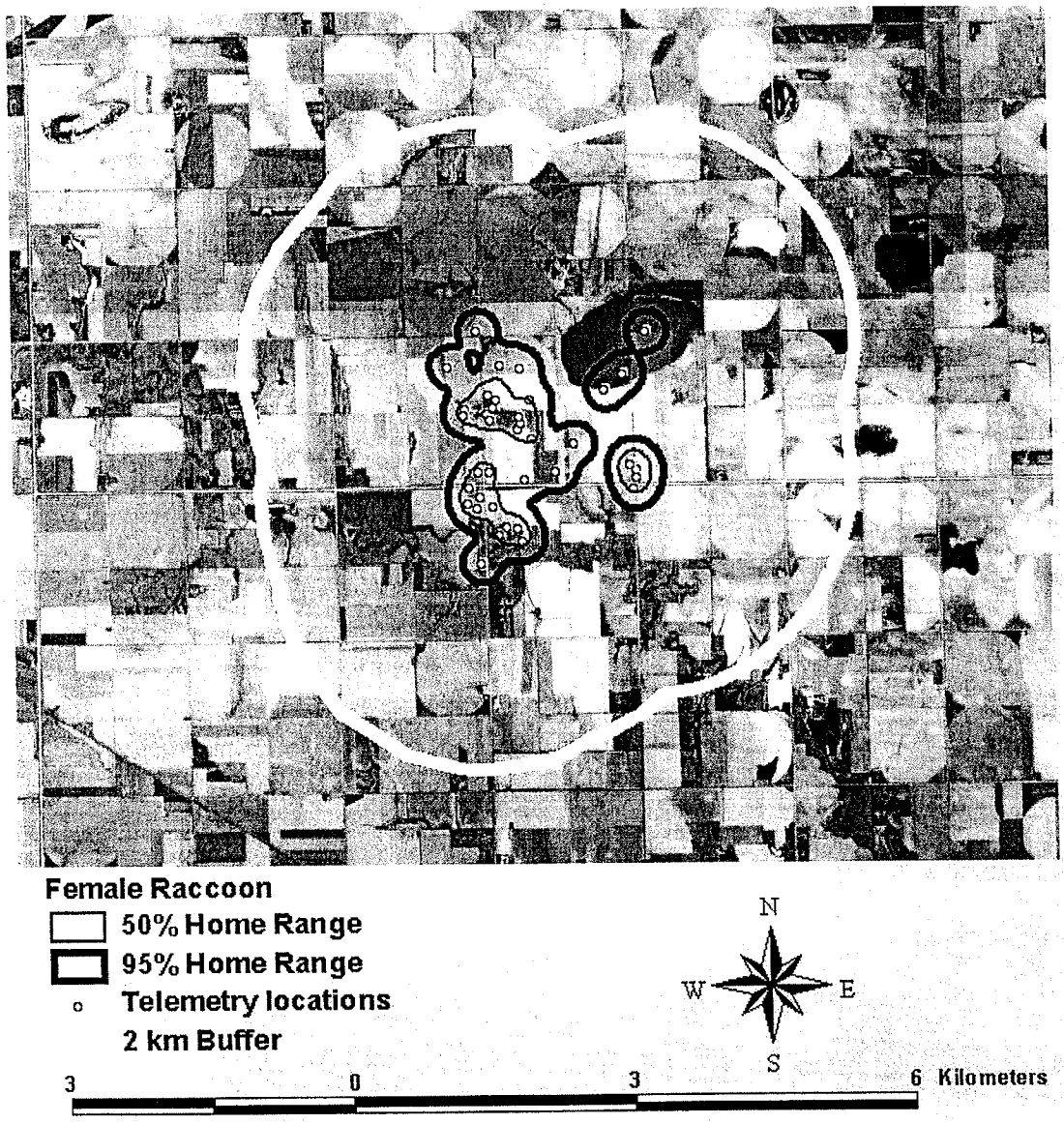


Figure 2. Example of a female raccoon home range, calculated using fixed kernel methods, showing both the 50% and 95% use areas and 2 km buffer.



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CHAPTER 3. Mesopredator abundance in Rainwater Basin wetlands: effects of landscape composition and relationship to songbird productivity

Abstract: The Rainwater Basin wetlands of south-central Nebraska are isolated within a matrix of agriculture, resulting in varying habitat quality. Mammalian presence, and avian nest survival, may be influenced by characteristics of the landscape such as spatial arrangements and amount of upland habitat surrounding a wetland, presence or absence of wooded areas, and open water. We live trapped mesopredators during the songbird breeding season in 2002-2003 to document their composition and abundance of within and among 11 wetlands of various sizes (radius: <30 meters to 1 km) in Clay County, NE. We conducted nest searches to document songbird nest survival. In 2003, we also implemented track stations, perpendicular to searched transects, to more closely reflect predator activity near monitored songbird nests. We captured 43 and 35 individual mesopredators in 1345 and 1051 trap nights during 2002 and 2003 respectively. Dominant mesopredator species in the RWB, included raccoons (*Procyon lotor*), striped skunk (*Mephitis mephitis*), and Virginia opossums (*Didelphis virginiana*). We found 188 and 200 nests in 2002 and 2003, respectively, and pooled nest survival estimates for 2002 were significantly lower than estimates for 2003. Predator presence varied across all wetlands sampled, as measured by both capture and track indices. Thus, we proposed four *a priori* models, based to explain predator presence, and we used R^2 and AIC values to select the best model. Our habitat analysis suggested that in 2002, local variables better explained variation in predator presence, while landscape variables bette explained variation in predator presence in 2003. Local and landscape variables may account for variation in predator presence which in turn helps to account for variation in nest

survival. Differences in wetland habitat composition such as presence of trees, at some wetlands may have increased predators in 2003 but not affected nest survival because of high water levels. Our results suggest that landscapes with a diversity of habitat types are important in supporting a diverse mesopredator community. In addition, our study suggests that both local and landscape variables must continue to be considered in management decisions.

INTRODUCTION

Wetland restorations are critical management actions, especially in agriculture-dominated regions. Predator communities vary in response to land cover patterns as well as prey availability (Dijak and Thompson 2000). Conversion of native landscapes to agriculture has had a profound effect on mesopredator habitat quality and distribution; raccoons (*Procyon lotor*), for example, have expanded their range from their more limited historic ranges because of increased habitat diversity and availability of food (Allen 1987). Little is known about predator selection of prairie habitats and their subsequent influence on avian nest survival (Phillips et al. 2003).

The importance of a landscape perspective has recently become central to management decisions made to improve avian nest survival (Stephens et al. 2003). Characteristics of the local patch, such as wetland patch size or amount of grassland or untilled, upland habitat available for nesting, may influence nest survival (Clark et al. 1999). Naugle et al. (2001) reported that several wetland bird species were more likely to inhabit wetlands in eastern South Dakota landscapes where <50% of the surrounding upland matrix was under tillage. Shutler et al. (2000) found higher numbers and higher

diversity of upland birds when near wetland patches in an agricultural dominated landscape. Patch size may also influence nest survival. For example, a high number of nests, concentrated into a small habitat patch, may increase predation susceptibility (Rohwer et al. 1997). Conversely, a large, contiguous patch may provide some protection from mid-sized mammalian predation because of the effort and energy expended needed to search a large area (Kuehl and Clark 2002).

The RWB covers approximately 11,000 km^2 in central Nebraska and is named for the natural playa wetlands that dominate the landscape. Historically, there were nearly 4000 wetlands in this region but today there are fewer than 400 remaining, isolated within a highly fragmented agricultural landscape (LaGrange 1997). These remaining wetlands vary in size and in quality of suitable habitat available for songbirds and their medium sized predators (mesopredators) due to differences in vegetation composition, relative amount of upland, and spatial characteristics (Gilbert 1989).

The US Fish and Wildlife Service and the Nebraska Game and Parks Commission currently manage approximately 12,000 hectares of wetlands and associated upland habitat. Many privately owned wetlands have little associated upland habitat, but restoration projects on publicly owned wetlands have resulted in significant improvements in the surrounding landscape. Nonetheless, the boundaries of a wetland's associated habitat with the surrounding agricultural habitat are abrupt.

Our goal was to determine factors that influence the abundance of mesopredators in wetlands throughout the landscape, as well as to assess relationships between mesopredator abundance and avian nest survival. Our objectives were to 1) document the composition of mesopredators in wetlands of the RWB, 2) relate mesopredator presence

to specific landscape characteristics, and 3) relate mesopredator presence to songbird survival.

We hypothesized that mesopredator abundance in a particular wetland could be driven by both local patch variables (e.g., patch size) and landscape variables (e.g., composition of adjacent habitats). Certain spatial arrangements of the landscape may enhance or hinder the mesopredator community's ability to isolate and prey upon bird nests and breeding birds. We hypothesized that avian nest survival would be negatively correlated with mesopredator abundance in a given wetland. Therefore, higher predator abundance in a wetland should result in lower songbird nest survival rates.

METHODS

Study area

We conducted this study from May to July during 2002 and 2003, coinciding with the songbird breeding season. Our 13- by 18-km study area (~30,000 ha) was located in Clay County, in south-central Nebraska, just southeast of Clay Center, Nebraska (40°31′37″N, 98°03′13″W, Figure 1). The RWB wetlands are wind-formed, clay-bottomed depressions that are filled by precipitation and run-off and are most often noted for their importance to migrating waterfowl, sandhill cranes (*Grus canadensis*), and the endangered whooping cranes (*Grus Americana*) during spring migrations (LaGrange 1997). They are also valuable as breeding habitat for many species of birds.

We chose eleven proximal wetlands as study sites, encompassing a range of sizes and area of surrounding grassland, upland habitat. We included six public (5 Federal Waterfowl Production Areas and 1 State Wildlife Management Area) and five private

wetlands in this study (Table1). The land use in our study area was predominantly agriculture (59% of area): corn, soybeans, and other row crops. The area also included grassland, hay, and pasture (9% of area), wetlands (17% of area), woodlands (2% of area), roads and associated ditch habitats (13% of area), and farmsteads (<1% of area). Average precipitation for this region during May – July from 1971 to 2004 was 32.5 cm. However, precipitation during this time in 2002 and 2003 was variable and lower than average (22.17 cm and 30.35 cm, respectively, High Plains Regional Climate Center, University of Nebraska-Lincoln). Mesopredators known to inhabit this region include raccoons (*Procyon lotor*), striped skunks (*Mephitis mephitis*), Virginia opossums (*Didelphis virginiana*), American badgers (*Taxidea taxus*), mink (*Mustela vison*), red fox (*Vulpes vulpes*), coyote (*Canis latrans*), and feral cats (*Felis catus*).

Field methods

We conducted live trapping on each wetland for a 4-5 day period, twice between May and July each year. To maximize captures, we chose trap sites within each wetland based on presence of animal tracks or other signs of mesopredators using the specific area (Chamberlain and Leopold 2002, Sargeant et al. 1993). We baited the traps primarily with sardines or anise oil, but we occasionally used chicken livers or fish oil (M. Phillips, Northern Prairie Wildlife Research Center, F. Pogmore USDA, and R. Bischof NGPC, personal communications). Coordinates of each trap site were recorded using a WAAS enhanced, handheld GPS receiver. Traps were set between 1600 and 2000 and checked between 0700 and 1000. We weighed, sexed, and ear tagged all captured animals. We anesthetized captured animals with inhaled isoflurane (MWI Veterinary Supply Co.,

Nampa, ID) using a portable anesthesia machine (R.B. Heath, DVM, Seven Seven Anesthesia, Fort Collins, CO) to provide anesthesia at the capture location. After marking with ear tags, animals were released at their capture location usually within 30 minutes. The University of Nebraska-Lincoln's Institutional Animal Care and Use Committee (IACUC) approved our research methods prior to our field work (IACUC Permit # 01-12-075).

To document songbird survival and predation events, we concentrated nest searches along a randomly placed transect, bisecting each study wetland. Transect lengths were equal to the diameter of each wetland. Small wetlands were completely searched and did not require a transect. Nests were monitored every 3-4 days and nest disturbances were recorded when observed. A nest was considered successful if at least one nestling survived to fledge.

We placed mammal traps in areas meant to facilitate captures for a concurrent radio-telemetry study (Chapter 2) therefore traps in larger wetlands were not proximal to monitored nests. So, during 2003, we implemented track stations to more closely reflect predator activity near monitored songbird nests. Each 1 m^2 track station was constructed out of fine-grained masonry sand mixed with mineral oil (5:1 sand to oil ratio) to keep the sand moist, retain animal tracks, and resist wind damage (Kuehl and Clark 2002, R. Bischof, Nebraska Game and Parks Commission, personal communication). We secured an unscented plaster egg in the center of each station to act as an interest point or novelty item. Our goal was to avoid rewarding the predator, which might bias our nest survival study; scented novelty items could potentially condition the animal to search the area (Kuehl and Clark 2002).

We placed six track stations on each wetland. At both ends of the transect, three track stations were placed 30 m apart, in a line perpendicular to the transect. Because small wetlands were not large enough to support a transect or 6 stations, we randomly placed 3 stations perpendicular to the wetland-upland interface. Track stations were monitored every 3-5 days and repaired as necessary. We regularly removed encroaching vegetation by hand. When a track was detected, length and width measurements were recorded and tracks were identified to species whenever possible.

Statistical analysis

We estimated daily nest survival rates using procedures developed by Mayfield (1975) within program MARK (White and Burnham 1999). Program MARK provides Akaike's Information Criterion (AIC) values to compare competing models. We considered two models in these analyses 1) nest survival pooled across all study sites (one survival estimate) and 2) nest survival estimated for each individual study site. To assess the impact of nest mortality on nest success, we extrapolated the daily nest survival estimates to the 23^{rd} power to calculate the probability of a nest surviving 23 days (incubation and nestling stages for red-winged blackbirds).

We calculated a yearly predator capture index for each wetland by dividing the number of captures by the total number of trap nights for the entire study area or specific wetland. Similarly, we calculated a track index, using data collected from track stations.

We prepared a GIS land cover layer for our study area by modifying the 2002 National Agricultural Statistics Service (NASS) cropland data layer (30 m resolution). We used the National Wetland Inventory (US Fish and Wildlife Service) coverage to

delineate wetland boundaries and added farmsteads and wooded areas from our observations and aerial photographs. Last, we field verified the cropland data during 2003 to note changes in rotations. The GIS data were stored, edited, and analyzed using ArcView 3.2 and ArcGis 8.0 (ESRI, Redlands CA, USA). We used seven dominant habitat classifications in our analyses: 1) corn, 2) soybeans and other row crops, 3) grassland/hay/pasture, 4) woodland, 5) farmsteads, 6) wetlands, and 7) roads and associated ditch habitats.

We determined four *a priori*, multiple regression models, based on nine parameters (the seven habitat variables listed above as well as wetland size and upland size of each study site, determined using GIS), to explain predator presence. Two of the four models were based on our interest in comparing local vs. landscape variables. Thus, the local model included two variables: wetland size and upland size. The landscape model included the seven compositional habitat variables from our GIS analysis: the proportion of corn, soybeans and other row crops, grassland/hay/pasture, woodland, wetland, farmsteads, and roads and associated ditches with a 1-km buffer around each wetland. The last two *a priori* models were based on the results of our habitat preference analysis of radio-marked animals (Chapter 2). The home range preference model included four landscape composition variables that were preferred by skunks, raccoons, and opossums within their home ranges (Chapter 2): proportion of surrounding landscape in corn, grassland/hay/pasture, wetlands, and woodland. The available landscape preference model was similar to the previous model, but included the four variables preferred by skunks the three species, within a larger landscape surrounding their home range (Chapter 2): corn, roads and associated ditches, wetlands, and woodland. We used

R^2 and AIC values to select the best model. We conducted regression analyses in SAS (SAS Institute 1990) to quantify relationships between predator abundance and nest survival for each wetland.

We calculated Spearman's Rank and Pearson's correlations (SAS Institute 2000) to rank nest survival, capture indices, and track indices for both 2002 and 2003, to accommodate small sample sizes and resulting non-normal data.

RESULTS

Songbird survival

We found 188 and 200 nests in 2002 and 2003, respectively; the most frequently found was red-winged blackbird nests (2002:166, 2003:182). However, we also encountered yellow-headed blackbird (*Xanthocephalus xanthocephalus*), mourning dove (*Zenaida macroura*), and dickcissel (*Spiza americana*) nests in both years. Eastern Kingbird (*Tyrannus tyrannus*), willow flycatcher (*Empidonax traillii*), and mallard (*Anas platyrhynchos*) nests were unique to 2002 and American coot (*Fulica americana*) and blue-winged teal (*Anas discors*) nests were unique to 2003. Brown-headed cowbirds (*Molothrus ater*) parasitized 48 (29%) and 47 (26%) nests in 2002 and 2003, respectively. Pooled daily nest survival rates were 0.9448 (95% CI: 0.9327–0.9549) in 2002 and 0.9543 (95% CI: 0.9475–0.9635) in 2003 (Table 2), which correspond to 23-day survival rates of 27% and 36%, respectively.

Predator index

We captured 43 and 35 individual mesopredators in 1345 and 1051 trap nights during 2002 and 2003 respectively. Our sample included raccoons (2002:10, 2003:8), skunks (2002:12, 2003:11), opossums (2002:17, 2003:14), and others (American badger, mink, and feral cats). Capture indices (captures per trap night) for the three dominant species did not fluctuate extensively between the two sampling years or between different species (raccoon: 0.009 [95% CI: ±0 .006], 0.008 [95% CI: ±0.005]; skunk: 0.011 [95% CI: ±0.006], 0.011 [95% CI: ±0.006]; opossum: 0.016 [95% CI ±0.007], 0.012 [95% CI: ±0.007], in 2002 and 2003, respectively). During 2003, we monitored track stations over 1534 exposure nights. The track indices for skunks (tracks per exposure night), in 2003, was 0.007 (95% CI: ±0.004), which was similar to capture indices. Raccoons were trapped slightly less often than they were documented at track stations (0.019, 95% CI: ±0.007). Opossums were trapped more often than their presence was documented at track stations (0.003, 95% CI: ±0.003). Predator presence varied across all wetlands sampled, as measured by both capture and track indices (Table 2).

Local and landscape models

In 2002, the best *a priori* model was the local model: Capture index 2002 = 0.0331 – 0.0006•wetland size + 0.001•upland size ($F_{2,10} = 1.80$; $R^2 = 0.311$; $P = 0.23$, Table 3). Variability in the capture index among wetlands in 2003 was best explained by our seven-variable *a priori* landscape model: Capture index 2003 = -0.086 + 0.001•corn – 0.0002•soybeans and other row crops + 0.001•grassland/hay/pasture + 0.032•woodland - 0.121•farmsteads -0.003•wetland + 0.106•road ($F_{7,10} = 1.08$; $R^2 = 0.72$; $P = 0.52$, Table

3). Finally, variability in the track index in 2003 was also best explained by our *a priori* landscape model: Track index 2003 = 1.533 - 0.015•corn – 0.014•soybeans and other row crops – 0.013•grassland/hay/pasture – 0.069•woodland + 0.361•farmsteads – 0.011•wetland – 0.094•road ($F_{7,10} = 14.20$; $R^2 = 0.97$; $P = 0.03$, Table 3).

Predator index versus nest survival

Results of our regression analyses based on ranked data for predator presence and nest survival exhibited similar trends in both years for capture indices as well as track indices (Figure 2). Generally, higher predator presence corresponded to lower nest survival. We removed one outlier from each plot, which improved R^2 and P values (Table 4). The same trends existed in the data before removing the outlier (Table 4); removed wetlands exhibited both higher predator presence and high nest survival. We removed one of our largest wetlands (Smith WPA) from the 2002 capture index analysis; trap sites on this wetland were not located near monitored nests and water was present near trap sites, potentially accounting for high predator presence. We removed a smaller wetland (PrivateK) from the 2003 capture index analysis; high water levels in this wetland provided protection for the songbird nests, while the wetland's roadside location provided easily accessed, prey items along its roadway edge (where we trapped). Finally, Greenhead WMA was removed from our analysis of track indices and nest survival; three track stations were placed along a wooded edge, where significant mesopredator activity was noted but again high water levels in the wetland may have prevented access to the nesting songbirds.

DISCUSSION

Predator abundance and nest survival varied considerably among wetlands in the Rainwater Basin (Table 2), reflecting local and landscape variability of habitat composition and quality. Fewer individuals were captured in 2003 than in 2002 because we reduced the number of traps set per wetland in 2003. We eliminated the smallest traps, as they did not catch any predators in 2002; we also used species-specific baits (sardines for skunks and opossums and anise oil for raccoons), reducing non-target species captures such as muskrats, feral cats, and other small mammals. Higher water levels in June and July of 2003 also reduced the number of nights we were able to set traps.

Differing water levels in the RWB in 2002 and 2003 may have affected nesting bird survival. Individual wetlands exhibited varying nest survival rates across wetlands during both years (Table 2). Pooled nest survival estimates for 2002 were lower than estimates for 2003. Most of the wetlands were completely dry by the end of the sampling season in 2002, which likely facilitated predator search efforts, especially in the smaller wetlands. In 2003, considerably higher water levels may have served to exclude foraging mammals from wetlands they had been able to access in 2002; songbirds may have had some protection from predators in the flooded centers of our study wetlands, resulting in higher nest survival (Table 1 and Table 2). In addition, the high water levels in 2003 often filled the roadway ditches, providing an easily accessible, potential alternative-prey (invertebrates, amphibians) foraging site for mesopredators, reducing predation pressure on songbirds.

Local and landscape variables accounted for variation in predator presence in our study. In turn, predator abundance accounted for some variation in nest survival. Red-winged blackbird productivity has responded to habitat quality and nest predator levels in other studies (Vierling 1999, Vierling 2000). Our habitat analysis suggested that in 2002 local variables better explained variation in predator presence, while landscape variables better explained variation in predator presence in 2003. Because of the high water levels in 2003, wetland and upland sizes became less important; high water levels encroached on the upland habitats while increasing available wetland areas. Water and associated food items also were available in roadside ditches and agricultural fields.

Our analysis also suggested that no single habitat type can accurately predict abundance, likely a reflection of their opportunistic nature (Allen 1987, MacClintock 2002). Skunks and raccoons prefered wetland habitats (Chapter 2), potential patches that serve as additional sources of prey. Dijak and Thompson (2000) reported that agricultural landscapes with available sources of water can support high densities of raccoons. Kuehl and Clark (2002) determined that the most important variable influencing skunk activity was the number of wetlands in the surrounding habitat in their study in northern Iowa.

Predator presence and nest survival (Figure 2) exhibited similar negative relationships in both years for capture indices as well as track indices. Each analysis had one major outlier; although removing it resulted in improved fit of the model, the outliers had biological explanations. We placed track stations closer to monitored songbird nests, and track stations were probably more accurate than our trapping data in providing a measure of the predators impacting the sample of nests.

It was difficult to show a close relationship between predator abundance and nest survival. We did not expect to be able to explain all of the variability in nest survival rates simply with mesopredator abundance because other nest predators are important (Nack 2002, Renfrew and Ribic 2003, Pietz and Granfors 2002). Our results suggest that mammalian predators do have a negative impact on songbird nest survival in the RWB region of Nebraska. Differences in wetland habitat composition such as presence of trees at some wetlands may have increased mesopredators in 2003 but not affected nest survival because of high water levels. Further investigation is necessary to determine the relative effects of mesopredators because other nest predators such as small mammals, raptors, and snakes (Pietz and Granfors 2000, Renfrew and Ribic 2003) certainly impact nest survival in this region. Multi-species, multi-guild predator studies suggest that predator management that is focused on only one predator guild may not significantly increase nest survival rates (Nack 2002, Renfrew and Ribic 2003) for the long term. The effects of habitat are also difficult to distinguish because of environmental stochasticity (Stephens et al. 2003). For example, variability in precipitation may have affected our ability to show relationships between habitat and predator abundance.

Most nest survival studies, including ours, rely on visual cues left at the nest to identify nestling fate. However, Pietz and Granfors (2000) used miniature video cameras to determine that empty nests exhibiting no evidence of disturbance may actually have been predated. Similarly, nests that have tipped or fallen apart may not have disturbed by a predator. We recommend that further studies on nest survival in the RWB employ video cameras to determine the entire suite of nest predators.

Herkert et al. (2003), Kuehl and Clark (2002), and Phillips et al. (2003) suggested that nest survival can be more efficiently improved through emphasis on habitat management. Our results suggest that landscapes with a diversity of habitat types are important in predicting mesopredator abundance and both local and landscape variables must be considered when making management decisions. Biologists can improve the RWB landscape to benefit songbird survival by continuing efforts to remove trees adjacent to wetland edges, by promoting upland areas with grassland habitat, and by managing for water levels that will enhance nest protection. These management goals can promote restoration of the RWB landscape so that it more closely resembles the pre-agricultural landscape.

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Table 1. Size comparisons for all study sites sampled in the Rainwater Basin region of south-central Nebraska, including wetland size and wetland size including grassland, upland habitat.

Wetland	Size (ha)	Size w/upland (ha)
Massie (WPA)	224.44	342.92
Smith (WPA)	117.08	192.54
Meadowlark (WPA)	3.59	31.96
Greenhead (WMA)	26.13	27.51
Green Acres (WPA)	17.45	25.77
Harms (WPA)	16.04	24.28
PrivateC2	10.4	10.4
PrivateK	6.72	6.72
PrivateA	6.2	6.20
PrivateC1	0.94	0.94
PrivateS	0.47	0.47

Table 2. Daily nest survival rates (95% confidence interval), calculated by program MARK, and predator indices (predators per night, ± 95% confidence interval) for each study site, each year in the RWB, of south-central Nebraska. Predator capture indices were calculated by dividing the number of predators captured by the total number of trap nights. Track stations were implemented in 2003 and track indices were calculated by dividing the number of predator incidences by the number of exposure nights.

	2002		2003		
Wetland	Daily nest survival	Capture index	Daily nest survival	Capture index	Track index
Massie	0.889 (0.0.77-0.95)	0.032 (0.025)	0.934 (0.89-0.96)	0.048 (0.038)	0.052 (0.027)
Smith	0.981 (0.94-0.99)	0.043 (0.034)	0.925 (0.89-0.95)	0.037 (0.032)	0.031 (0.024)
Meadowlark	0.962 (0.94-0.98)	0.071 (0.060)	0.961 (0.95-0.97)	0.023 (0.031)	0.070 (0.013)
Greenhead	0.926 (0.88-0.96)	0.031 (0.027)	0.984 (0.96-0.99)	0.023 (0.026)	0.086 (0.051)
Green Acres	—[a]	0.019 (0.027)	—[a]	0.019 (0.026)	0.029 (0.023)
Harms	0.951 (0.92-0.97)	0.032 (0.028)	0.954 (0.91-0.98)	0.033 (0.037)	0.017 (0.024)
PrivateC2	0.962 (0.89-0.99)	0.012 (0.017)	0.962 (0.94-0.98)	0.029 (0.028)	0.011 (0.015)
PrivateK	0.895 (0.85-0.93)	0.067 (0.063)	1.000 (0.90-0.99)	0.061 (0.067)	0.000 (0.000)
PrivateA	0.889 (0.76-0.95)	0.038 (0.029)	0.897 (0.80-0.95)	0.045 (0.038)	0.033 (0.032)
PrivateC1	0.956 (0.84-0.99)	0.013 (0.025)	—[a]	0.000 (0.000)	0.057 (0.054)
PrivateS	0.955 (0.90-0.98)	0.017 (0.032)	0.891 (0.74-0.96)	0.026 (0.051)	0.033 (0.032)

[a]no nests found

Table 3. A priori models of predator presence based on capture indices for 2002 and 2003 and track indices for 2003. Model parameters were chosen based on data from a concurrent study of mesopredator habitat preferences (defined by home range area) and available habitats in the landscape (defined by a species-specific buffer surrounding the home range, raccoon = 2 km and skunk = 1.4 km) in the RWB region of south-central Nebraska. Best fitting models were chosen based on a combination of R^2 values and lowest AIC ranks and are marked with "**".

	Year	Model name	# parameters	AIC	R^2	*P*-value
Capture index	2002	Local effects**	2[a]	14.83	0.31	0.23
	2002	Landscape effects	7[b]	23.38	0.40	0.92
	2002	Habitat preference: HR	4[c]	18.11	0.35	0.56
	2002	Habitat preference: landscape	4[d]	21.53	0.12	0.93
Capture index	2003	Local effects	2[e]	12.66	0.15	0.52
	2003	Landscape effects**	7[f]	10.66	0.72	0.52
	2003	Habitat preference: HR	4[g]	14.82	0.28	0.68
	2003	Habitat preference: landscape	4[h]	12.52	0.42	0.44
Track index	2003	Local effects	2[i]	20.01	0.29	0.25
	2003	Landscape effects**	7[j]	-5.01	0.97	0.03
	2003	Habitat preference: HR	4[k]	23.94	0.30	0.66
	2003	Habitat preference: landscape	4[l]	23.36	0.33	0.59

[a]wetland size (-) and upland size (+); '(-)' indicates negative response, '(+)' indicates positive response

[b]corn (+), soybeans and other row crops (+), grassland/hay/pasture (+), woodland (+), farmsteads (+), wetlands (+), and roads (+)

[c]corn (-), grassland/hay/pasture (+), wetlands (-), and woodlands (+)

[d]corn (-), roads (-), wetlands (-), and woodlands (+)

[e]wetland size (+), upland size (-)

[f]corn (+), soybeans and other row crops (-), grassland/hay/pasture (+), woodland (+), farmsteads (-), wetlands (-), and roads (+)

[g]corn (+), grassland/hay/pasture (+), wetland (+), and woodland (+)

[h]corn (+), road (+), wetland (-), and woodland (+)

[i]wetland size (+), and upland size (-)

[j]corn (-), soybeans and other row crops (-), grassland/hay/pasture (-), woodland (-), farmsteads (+), wetlands (-), and roads (-)

[k]corn (-), grassland/hay/pasture (+), wetlands (-), and woodlands (-)

[l]corn (-), roads (+), wetlands (-), and woodlands (+)

Table 4. Results of regression analyses, for ranked nest survival and predator presence (both capture and track indices) as determined using Spearman's rank for the RWB region of south-central Nebraska.

Year	n[a]	Slope	Outiler removed[b]	R^2	p-value	Index
2002	9	-0.08	No	0.008	0.80	Capture index
2002	8	-0.23	Yes	0.09	0.44	
2003	8	-0.03	No	0.001	0.93	Capture index
2003	7	-0.48	Yes	0.23	0.23	
2003	8	-0.31	No	0.15	0.31	Track index
2003	7	-0.78	Yes	0.72	0.01	

[a]Wetland sample size varies, as sites with no available nests were removed from analyses

[b]No: all wetlands in analysis; Yes: one outlier removed.

Figure 1. Our study area was a portion of the Rainwater Basin region, located in south-central Nebraska.

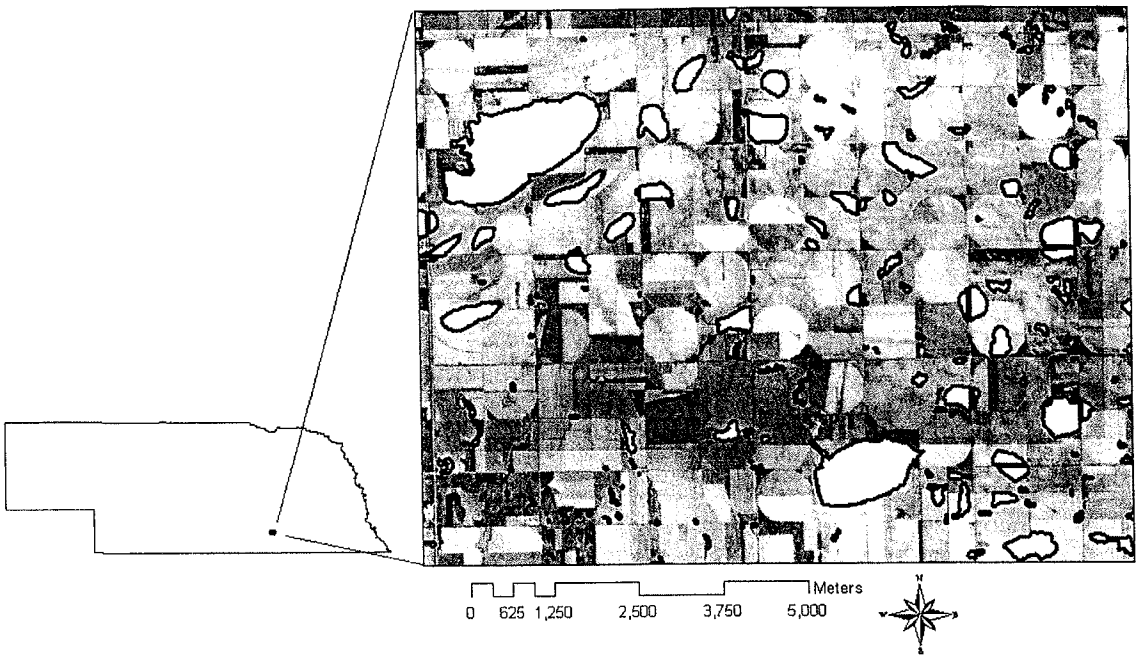
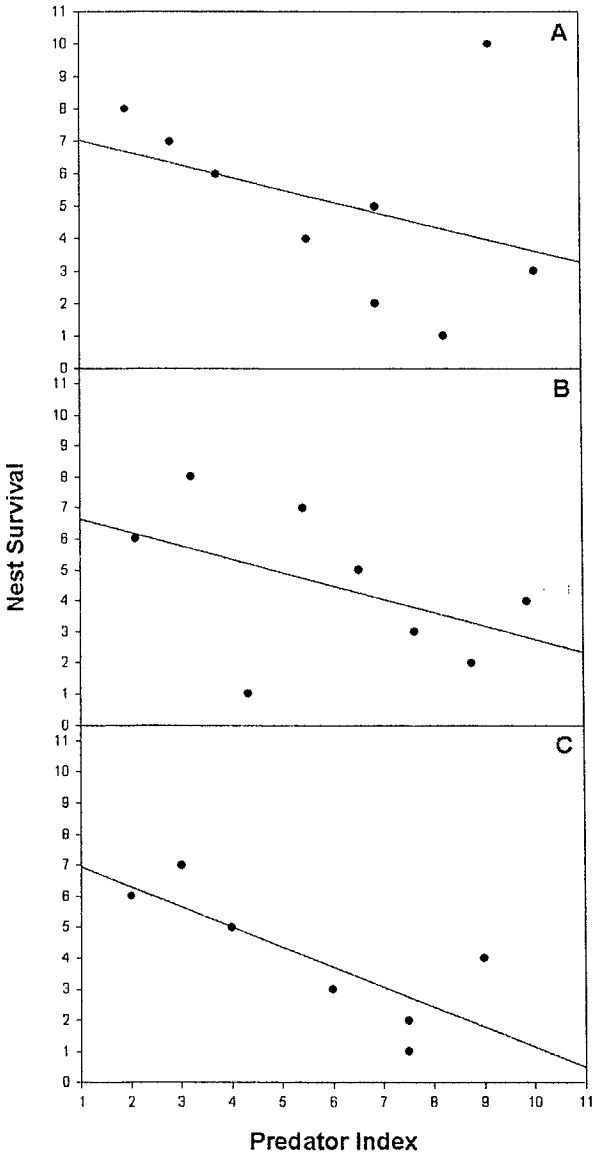


Figure 2. Relationship of ranks (lowest = 1, highest = 11) for nest survival and predator presence after removal of one outlier from each, for 11 wetlands in the Rainwater Basin region of south-central Nebraska.



A. Capture index versus Nest Survival, 2002

B. Capture index versus Nest Survival, 2003

C. Track index versus Nest survival, 2003

LITERATURE CITED

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